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IMPLICATIONS OF CLIMATIC CHANGE AND VARIABILITY FOR

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IMPLICATIONS OF CLIMATIC CHANGE AND VARIABILITY FOR ONTARIO'S AGRI-FOOD SECTOR

A Report Prepared for the
Atmospheric Environment Service
Environment Canada

by the Land Evaluation Group

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University School of Rural Planning and Development
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Guelph, Ontario

March 1986

Publication No. LEG-26



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**IMPLICATIONS OF CLIMATIC CHANGE
AND VARIABILITY FOR ONTARIO'S
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PREFACE AND ACKNOWLEDGEMENTS

The Land Evaluation Group (LEG) is an interdisciplinary team of scientists at the University of Guelph conducting research in the fields of land resource assessment and land use evaluation. The LEG has integrated research on land from the biophysical and socio-economic sciences, developed procedures for evaluating land for alternative uses, compiled the required data bases, and implemented computer-based land evaluation systems. An information base and associated analytical systems have been applied to several land use issues in Ontario. The LEG is currently expanding the range of issues the Ontario system can address, and extending the concepts and methodologies to other resource sectors and to other geographic scales.

The Atmospheric Environment Service (AES), Environment Canada commissioned the LEG to conduct an assessment of the implications of climatic change for the agri-food sector in Ontario (Contract Serial No. OSE85-00136), employing the framework developed in a preliminary study (LEG, 1985). The analyses investigate the extent to which a climatic change scenario supplied by the AES would enhance or constrain opportunities for and returns from agricultural production at the farm, regional and provincial levels in Ontario. The project draws upon the cumulative expertise of scientists affiliated with the LEG, Agriculture Canada and the AES.

The Ontario evaluation system was developed by the LEG for the Land Resource Research Institute (LRRI), Research Branch, Agriculture Canada with support from the Ontario Ministry of Agriculture and Food (OMAF). This project utilizes much of the information base and many of the analytical procedures developed for the Ontario system. In addition, these analyses draw upon land resource and economic performance data compiled for the Ontario Directorate of the Regional Development Branch (RDB), Agriculture Canada and a crop productivity modelling procedure implemented by the Crop Production Division of the RDB.

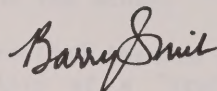
The LEG gratefully acknowledges the contributions and support of the Atmospheric Environment Service of Environment Canada, the Research and Regional Development Branches of Agriculture Canada, and the Ontario Ministry of Agriculture and Food.

Robert Place assisted with the development of a climatic classification system for horticultural crops, and its application to climatic change. Wayne Pfeiffer assisted with the application of the cash grain farm model. The LEG wishes to express its appreciation for these contributions.

The LEG is co-ordinated through the University School of Rural Planning and Development (USRP&D). The research team comprises scientists from the USRP&D, and the Departments of Agricultural Economics and Business, Computing and Information Science, Geography, Land Resource Science, and Mathematics and Statistics.

The following members of the Land Evaluation Group contributed to this phase of the project:

Deborah Bond
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Barry Smit
Project Director

EXECUTIVE SUMMARY

1 PURPOSE AND OVERVIEW

This project examines the implications of an altered climatic regime on agricultural production in Ontario. More specifically, it assesses the impacts of long-term climatic change associated with a doubling in atmospheric concentrations of CO₂ on agricultural production opportunities at the farm, regional and provincial levels.

The initial step in the project estimates the potential effects of an enriched CO₂ environment on agroclimatic resources throughout Ontario, and estimates variability in precipitation levels under the current and the altered climatic regime. These possible adjustments in climatic conditions pertinent to crop production are employed in subsequent steps of the study.

At the farm level, the analysis examines the potential impacts of changes in long-term climatic norms on the economic viability of a "typical" cash grain farm in South Western Ontario, and estimates the extent to which extremes in precipitation levels might affect farm profits under the current and altered climatic regimes.

At the regional level, the potential influence of climatic change and variability on the production opportunities for field and horticultural crops are assessed in each of six regions of the province. The analysis also appraises the prospects for introducing new crops to Ontario under the altered climatic regime.

The province-wide assessment examines the possible effects of an altered climate and alternative levels of precipitation on Ontario's potential for food production. The analysis measures the extent to which losses in production opportunities in one region might be offset by increases elsewhere, and thereby provides an aggregate assessment of the implications of climatic change on the provincial prospects for food production.

2 PROCEDURES, DATA AND ASSUMPTIONS

2.1 Agroclimatic Resources for Crop Production

2.1.1 Elevated CO₂ Levels and Climatic Change

Estimates of the potential impacts of a doubling in atmospheric concentrations of CO₂ on monthly normals for mean temperature and total precipitation are derived from a general circulation model and made available by the Atmospheric Environment Service (AES), Environment Canada. These data were used to estimate agroclimatic resources (e.g. growing season length, heat units, evapotranspiration) available for crop production in each of six regions of Ontario.

2.1.2 Variability in Precipitation Levels

Estimates of the current range in precipitation levels for each defined region in Ontario were derived using monthly precipitation levels recorded between 1951 and 1981. In the absence of information on the degree to which a 2 X CO₂ environment might affect variability in annual levels of precipitation, it is assumed that the relative range in precipitation about the norm for the growing season would not change.

2.2 **Farm Level Assessments**

A cash grain farm model is used to estimate the impacts of climatic change on resource allocation and product mix, and hence on farm profits. The analyses are conducted for a "typical" 200 hectare cash grain farm in South Western Ontario. The model is run for two scenarios. The first approximates current climatic and economic conditions, whereas the second assumes a climate altered by a doubling in CO₂, ceteris paribus. Yields for cash grains are adjusted to reflect the altered agroclimatic environment, and all other conditions including production costs and crop prices are maintained at initial levels.

The degree to which variability in precipitation implies a risk to crop production and farm profits is assessed by assuming decisions regarding the operation of the "typical" cash grain farm are based upon prevailing economic conditions and long-term climatic normals, then adjusting grain yields to those estimated for the extremes of precipitation. This provides a basis for judging the combined effects of climatic change and variability on crop production, value of production, and farm profits.

2.3 **Regional Assessments**

2.3.1 Field Crops

A crop productivity model is employed to estimate the extent to which thermal and moisture conditions combine to limit crop yields. Yield estimates are used in conjunction with economic data on production costs, crop prices, and estimates of land available for crop production to trace the impacts of altered climates on production opportunities for seven field crops on seven types of land in each region of Ontario.

Initially, yield responses to changes in long-term climatic norms are estimated by adjusting those input parameters of the crop productivity model which are sensitive to a 2 X CO₂ atmosphere. Then, the effects of precipitation extremes under the current and altered climates are estimated by a similar procedure.

2.3.2 Horticultural Crops

A climatic rating scheme is employed to evaluate the effects of changes in climatic norms on the production opportunities for horticultural crops. Horticultural crops are divided into frost-sensitive and winter-temperature-sensitive crops. Corn heat units are used as the primary criterion to appraise climatic potential for these crops. Length of frost-free season and extreme winter temperatures are used as secondary criteria for frost-sensitive and winter-temperature-sensitive crops respectively.

2.3.3 New Crops

A preliminary assessment of the opportunities for introducing new crops to Ontario under the altered climatic regime is based upon identifying areas in the United States where climatic conditions are presently similar to those anticipated in South Western Ontario under the altered climatic regime, and by identifying viable crops in these areas. Climatic conditions in Ohio, Illinois, Indiana and Maryland compared favourably to those estimated for South Western Ontario. Information on crop production in these states is obtained from state and federal statistical summaries.

3 EFFECTS OF A DOUBLING IN CO₂ ON AGROCLIMATIC RESOURCES IN ONTARIO

3.1 Climatic Normals

A doubling in atmospheric concentrations of CO₂ would result in considerable increases in growing season length, mean daytime temperatures, accumulated corn heat units, precipitation and potential evapotranspiration. The anticipated climate in Northern Ontario would in many ways resemble the current climate in South Western Ontario, whereas the altered climate in the southern parts of Ontario would be comparable with current climatic conditions in southern portions of Illinois, Indiana and Ohio. In many parts of Ontario, the agricultural benefits of increases in precipitation would be negated by even larger increases in potential evapotranspiration.

3.2 Variability in Precipitation

The combination of expected increases in precipitation and a longer growing season would be expected to result in substantial increases in average levels of total precipitation during the cropping season. The altered climatic regime would also be characterized by a considerable increase in the distribution of yearly levels of precipitation around the future norms.

4 EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON CROP PRODUCTION AND ECONOMIC OPPORTUNITIES AT THE FARM LEVEL

Long-term changes in climatic normals could have profound effects upon cash grain farming in South Western Ontario. Substantial increases in farm profits would be possible, but this would require a greater reliance upon grain corn production. The vulnerability of monoculture farming systems to market fluctuations and to diseases and pests, as well as the potential adverse impacts of continuous row cropping on land quality, raises several questions regarding the long-term sustainability of such a farm enterprise. Furthermore, fluctuations in annual farm profits attributable to precipitation extremes would tend to increase under the altered climate. This instability could trigger additional problems at the farm level including inadequate cash flow and increases in debt load.

5 EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON REGIONAL CROP PRODUCTION OPPORTUNITIES

5.1 Production Opportunities for Field Crops

In Northern Ontario, the array of crops that could be grown under the altered climatic regime would be expanded to include grain corn, wheat and soybeans. Furthermore, yield levels for the forages and cereal grains that are currently grown in Northern Ontario would increase substantially. Variations in precipitation from year to year however would pose a considerable risk to crop production in Northern Ontario. Generally, the drier years would limit production on lands with a lower tolerance to droughtiness; but these losses would be countered by enhanced prospects on lands with relatively high moisture reserves. The opposite would be expected in years with above average levels of precipitation.

In the more southerly parts of Ontario, moisture stress associated with the longer and considerably warmer summers would impinge upon the production opportunities for most field crops, despite the longer growing season. The greatest impacts would occur on well to excessively well-drained lands during the drier years. However the altered thermal regime, coupled with greater than average levels of precipitation during the crop growing season, would enhance the production opportunities for many field crops.

5.2 Production Opportunities for Horticultural Crops

The longer, warmer growing seasons and the milder winters associated with elevated levels of CO₂ would expand the opportunities for producing horticultural crops throughout Ontario. It would be feasible to produce frost-sensitive crops such as sweet corn throughout the province. The production prospects for crops sensitive to extreme winter temperatures would also be improved; the commercial production of apples, for example, would be possible throughout the province. The anticipated increases in summer and winter temperatures would be sufficient to allow the production of tender fruits such as grapes in most areas of Central, South Central, Western and South Western Ontario; but the

altered climates in Eastern and Northern Ontario would continue to be unsuitable for these crops.

5.3 Production Opportunities for New Crops

It would appear that the opportunities for introducing new crops to Ontario under the altered climatic regime would be quite limited. Potential benefits of these climatic changes would probably be noticeable in two areas. First, the longer season and higher yielding cultivars that are currently used in the Central United States would in all likelihood be suitable to Ontario. Second, the warmer temperatures, especially during the winter months, will be much more favourable for fruits and vegetables, and production would not be limited to lakeside locations. It should be feasible to produce a wide range of horticultural crops over large portions of the province under the altered climatic regime.

6 EFFECTS OF CLIMATIC CHANGE ON ONTARIO'S FOOD PRODUCTION POTENTIAL

Risks to agricultural production in Ontario would increase substantially given the specified changes in climate, especially in those years with low precipitation levels. Changes in long-term normals would contribute to a modest decline in production potential, but these opportunities could be recouped in those years with a higher than average level for precipitation during the growing season. The largest risk is associated with drier than average years. Relatively dry years currently impinge upon provincial opportunities for food production. Low levels of precipitation, combined with the estimated increases in long-term temperature normals, would impose severe constraints on crop production opportunities and could threaten the security of Ontario's food supply.

7 DIRECTIONS FOR FUTURE RESEARCH

This study has demonstrated some of the complexities involved in attempting to assess socio-economic implications of climate changes. Considerable research is needed to better appreciate the implications of climatic changes for agriculture and rural economies in Canada. Some of the important directions for future research include:

- development of analytical procedures,
- crop yield responses to biophysical conditions,
- farm and regional adjustments and sensitivities,
- intersectoral links and implications,
- interprovincial and international assessments and comparative advantage, and
- response options and policy implications.

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1 INTRODUCTION

1.1 Climate Impact Assessment

The prospect of substantial increases in atmospheric concentrations of CO₂ and its long-term consequences for climate has stimulated considerable interest in the interactions between climate and society (for example, Chen et al., 1983; Kates et al., 1984; National Research Council, 1983; Parry, 1985). These interactions tend to be very complex, traverse international boundaries and involve many segments of society. The understanding of the relationships between climate and society is emerging as a new field of scientific investigation. Several approaches for examining the impacts of climate on society have been proposed and tested, but no single model has gained universal acceptance.

One approach to guide the development of our understanding of climate and society is characterized by two broad categories of research (Timmerman and Grima, 1985). The first category would systematically appraise the potential impacts of climatic change on individual sectors within society. Its principal contributions would include a clearer understanding of the pathways along which the impacts of climatic change are transmitted, and an assessment of "what-if" questions given the current relationships between climate and society. This would provide a foundation for the second category which would evaluate the aggregate effects of climatic change on the functioning of society. This would require an integrative approach based upon inter-sector and interregional appraisals, as well as the possible evolution of societal values and changes in climate-society relationships. These sorts of analyses would indicate the extent to which climatic change, in combination with long-term changes in other conditions, would either create opportunities or impose constraints for the overall well-being of society.

Assessments of the implications of climatic change on individual or multiple sectors of society commence with a statement describing the magnitude and direction of climatic change. For example, general circulation models have been employed to estimate at the broad scale the implications of elevated concentrations in CO₂ on climate. Alternatively, the analysis can be based upon parametric or incremental adjustments to particular climatic parameters. Regardless of the technique employed to specify changes in climate, it is crucial to recognize that the further development of impact assessment procedures must commence with a clear statement on the direction and magnitude of climatic change.

1.2 Project Purpose and Overview

This project falls within the first of the two research thrusts outlined in Section 1.1. It examines the implications of an altered climatic regime on agricultural production in Ontario. More specifically, it assesses the impacts of long-term climatic change associated with a doubling in atmospheric concentrations of CO₂ on agricultural production opportunities at the farm, regional and provincial levels.

The initial step in the project estimates the potential effects of an enriched CO₂ environment on agroclimatic resources throughout Ontario, and estimates variability in precipitation levels under the current and the altered climatic regime. These possible adjustments in climatic conditions are employed in subsequent steps of the study.

At the farm level, the analysis examines the potential impacts of changes in long-term climatic norms on the economic viability of a "typical" cash grain farm in South Western Ontario, and estimates the extent to which extremes in precipitation levels might affect farm profits under the current and altered climatic regimes.

At the regional level, the potential influence of climatic change and variability on the production opportunities for field and horticultural crops are assessed in each of six regions of the province. The analysis also appraises the prospects for introducing new crops to Ontario under the altered climatic regime.

The province-wide assessment examines the possible effects of an altered climate and alternative levels of precipitation on Ontario's potential for food production. The analysis measures the extent to which losses in production opportunities in one region might be offset by increases elsewhere, and thereby provides an aggregate assessment of the implications of climatic change on the provincial prospects for food production.

2 OVERVIEW OF ANALYTICAL PROCEDURES, DATA AND ASSUMPTIONS

The research strategy integrates separate models of climatic change, crop productivity and production opportunities into one comprehensive analytical system. It commences with an appraisal of the extent to which long-term normals for selected agroclimatic parameters might change given a doubling in atmospheric concentrations of CO₂, and estimates variability in precipitation given current and future climates. Subsequent steps assess the implications of these altered climates on food production opportunities, starting with an assessment at the farm level, then an examination at the regional level, and concluding with a province-wide appraisal. An overview of specific research tasks follows, and the links between tasks are identified.

2.1 Agroclimatic Resources for Crop Production

This step develops a link between the climatic change data and the climatic data required to judge the impacts of an altered climatic regime on crop productivities throughout Ontario. The climatic change data are derived from a general circulation model which operates at the broad scale and estimates possible adjustments in two climatic parameters. The required agroclimatic data span a wider range of climatic parameters and need to be compiled on a subprovincial basis. Furthermore, information on long-term variability in annual precipitation levels are not available. Procedures, data and assumptions used to estimate agroclimatic resources available for crop production in Ontario under the current and an altered climatic regime are summarized in this section.

2.1.1 Long-Term Normals

The analysis commences with an assessment of the extent to which a doubling in atmospheric concentrations of CO₂ would alter long-term climatic normals which influence crop productivities.

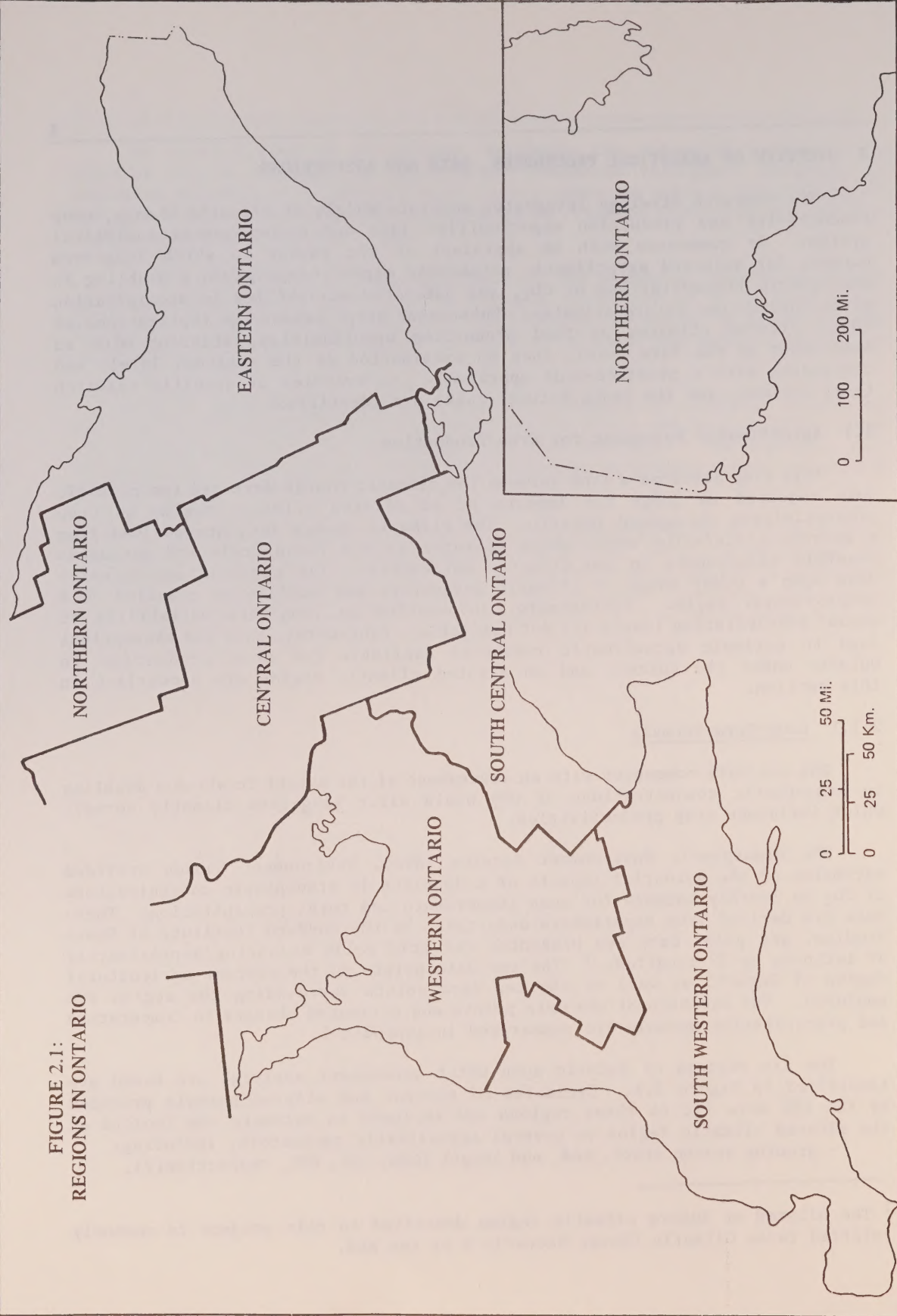
The Atmospheric Environment Service (AES), Environment Canada provided estimates of the potential impacts of a doubling in atmospheric concentrations of CO₂ on monthly normals for mean temperature and total precipitation. These data are derived from experiments undertaken by the Goddard Institute of Space Studies, and point data are presented for grid cells measuring approximately 4° latitude by 5° longitude.¹ The two data points in the current agricultural region of Ontario as well as the ten data points surrounding the region are employed. The location of the data points and estimated changes in temperature and precipitation normals are summarized in Appendix 1.

The six regions of Ontario upon which subsequent analyses are based are identified in Figure 2.1. Estimates of current and altered normals provided by the AES were fit to these regions and employed to estimate the impacts of the altered climatic regime on several agroclimatic parameters, including:

- growing season start, end, and length (GSS, GSE, GSL, respectively),

¹ The altered or future climatic regime described in this project is commonly referred to as Climatic Change Scenario B by the AES.

FIGURE 2.1:
REGIONS IN ONTARIO



- mean daily temperature during the GSL,
- accumulated corn heat units for the GSL,
- total precipitation for the GSL, and
- total potential evapotranspiration for the GSL.

This step in the analysis, and hence all subsequent steps, estimates the degree to which increases in CO₂ might affect agroclimatic resources for crop production. It does not consider changes in either conditions such as the direct impacts of elevated CO₂ concentrations on crop growth, alternative technologies or changes in other environmental-ecological factors.

Procedures employed to estimate the effects of a doubling in CO₂ on the relevant agroclimatic parameters are presented elsewhere (LEG, 1985, Section 2.2.2) and the findings are summarized in Appendix 2.

2.1.2 Variability in Precipitation Levels

The following five-step procedure and data sources are employed to estimate current variability in precipitation levels in each region of Ontario. Steps 1 through 4 utilize station data provided by the AES. Step 5 links these station data to precipitation normals estimated for each of the six regions in Ontario.

Step 1: The AES provided the Land Evaluation Group (LEG) with monthly precipitation levels for several climatic stations for the 1951-1981 period. The LEG selected a representative station for each region defined in Figure 2.1. Delhi was employed for South Western, South Central, and Western Ontario. Maniwaki is the representative station for Eastern and Central Ontario. Northern Ontario is represented by Sault Ste. Marie.

Step 2: The LEG employed the data for the representative stations to estimate total precipitation for the current growing season in each region for each year. Years with an incomplete record of total monthly precipitation were omitted. When required, daily precipitation rates were estimated assuming a uniform rainfall distribution for that month.

Step 3: For each region, annual estimates of total precipitation for the growing season were ranked, and the extreme ten per cent of this distribution over the 1951-1981 period was eliminated. The remaining years approximate the range in precipitation levels that could be expected nine years out of ten.

Step 4: Mean total precipitation for the growing season in each region was calculated using these data (i.e. nine years out of ten). High and low precipitation coefficients were estimated as the ratio of the defined extremes to the calculated mean.

Step 5: Mean total precipitation estimated using representative station data (i.e. Step 4) compared favourably to long-term precipitation normals. Hence, the high and low precipitation coefficients calculated in Step 4 are used to estimate variability about current precipitation normals.

The effect of a CO₂ doubling on variability in precipitation levels is currently unknown. In the absence of such information, it is assumed that the percentage or relative distribution of precipitation about the norm for the growing season would not change. Hence, monthly precipitation levels for 1951-1981 are employed, and the procedures outlined above are modified to account for the growing season length under the altered climatic regime.

Average, low and high levels of precipitation for each region under the current and altered climatic regime are summarized in Appendix 2.

2.2 Farm Level Assessments

The economic viability of a farm enterprise is determined by the complex interaction among a wide variety of biophysical and socio-economic factors such as soil and climatic conditions, capital investment, availability of short and long term financing, managerial skills, farm technologies, crop and livestock prices, labour availability and costs, and so on. This part of the project integrates the estimates of climatic changes outlined in Section 2.1 with a crop productivity model and a conventional farm production model. Data restrictions limit the application of the basic approach to one type of farming within a specific region of Ontario. The procedures are sufficiently flexible however that they could be applied to farm enterprises elsewhere.

An existing cash grain farm model (Pfeiffer, 1976) is employed to estimate the effects of climatic change on maximum net returns at the farm level, and on the optimal allocation of land, labour and capital resources available to the farm enterprise. The application of this farm model is summarized in this section, while further information is presented in Appendix 3.

The analyses are conducted for a "typical" cash grain farm in South Western Ontario. Land resources available for crop production are limited to approximately 200 hectares, of which 160 hectares are part of the farm enterprise while the remaining 40 hectares could be rented. All of the land is assumed to be well-drained and level. Production costs on this typical farm include fixed and variable costs such as land, hired labour, machinery operations, on and off-farm crop drying and so on. The major source of farm income is crop sales. All economic data are calibrated relative to conditions in 1977-1978.

The farm model employs linear programming procedures to estimate maximum returns and the optimal allocation of resources. It is run under two sets of conditions. The first approximates current climatic and economic conditions in South Western Ontario, whereas the second assumes a climate altered by a doubling in CO₂, *ceteris paribus*. A crop productivity model employed by the LEG (1985, Sections 2.2.3 to 2.2.5) estimates the impacts of the specified adjustments in climatic normals upon yields for cash grains. All other conditions such as production costs and crop prices are maintained at initial levels. Hence the analysis isolates the extent to which climatic change would induce a change in the profitability of this "typical" cash grain farm and its efficient allocation of resources (i.e. use of available land for crops, labour, etc.).

The farm level assessments also include an examination of the extent to which variability in precipitation implies a risk to crop production and profitability for the "typical" cash grain farm in South Western Ontario. Analyses are conducted assuming that decisions regarding farm operations are based upon prevailing economic conditions and long-term climatic norms, and assuming the variations in precipitation levels outlined in Section 2.1.2. and Appendix 2. The LEG's crop productivity model is used to estimate the effects of these deviations in precipitation on yields for each grain crop. This provides a basis for gauging the impacts of alternative levels of precipitation in combination with climatic change on total crop production, on farm income and on profitability.

2.3 Regional Assessments

Regional assessments conducted for this project are concerned with the influence of climatic change and variability on the long-term opportunities for crop production in each of the six regions of Ontario identified in Figure 2.1. These assessments identify the degree to which the altered climatic regime would enhance or jeopardize the potential for producing specific crops and do not represent a forecast of likely changes in patterns of land use. Information on climatic change described in Section 2.1 is considered relative to requirements for the production of several crops. The analyses are divided into three broad categories. Initially, the effects of a CO₂-induced climatic change and variability in precipitation on the biophysical and economic prospects for common field crops in Ontario are assessed. Then, the implications of specified changes in long-term climatic normals on the opportunities for selected horticultural crops is considered. The regional assessments conclude with an appraisal of the prospects for introducing new crops to Ontario under the altered climatic regime. A summary of the procedures, data and assumptions employed in each of the categories follows.

2.3.1 Field Crops

A crop productivity model, in conjunction with data on yield levels required to provide a positive return to investment and on the availability of land for field crop production in each region of Ontario, is employed to trace the impacts of climatic change and variability in precipitation on production opportunities for field crops.

The crop productivity model and its capacity to estimate yield response to climatic change is described elsewhere (LEG, 1985, Sections 2.2.2 and 2.2.5). In this project, it is employed to estimate the impacts of the altered climatic regime on yields for seven field crops (Table 2.1) on seven types of land (Table 2.2) in each region.

TABLE 2.1: FIELD CROPS

Grain Corn	Soybeans
Barley	Hay
Oats	Fodder Corn
Winter Wheat	

TABLE 2.2: OVERVIEW OF THE LAND CLASSIFICATION SYSTEM

Ontario's land resources are classified according to their biophysical characteristics that are relevant to the production of crops. The seven-tier classification system used in this report is summarized below.

LAND TYPE	BIOPHYSICAL CHARACTERISTICS
A	- well-drained loamy soils - relatively level topography
B	- fine-textured clays - moderately well to well-drained
C	- coarser-textured sands and gravel, or shallow soils (less than 1 metre to bedrock) - well to excessively well-drained
D	- imperfectly drained soils which have been tile drained
E	- imperfectly drained soils which have not been tile drained, and all poorly to very poorly drained soils
F	- extremely stony or shallow soils
G	- well-drained loamy soils - rolling to hilly topography

Initially, yield responses to changes in long-term climatic norms are estimated. This involves adjusting the input parameters to the crop productivity model which are sensitive to a 2 X CO₂ atmosphere (i.e. growing season length, mean daily temperature, accumulated corn heat units, precipitation and potential evapotranspiration). Other factors influencing productivity, including location of the ground water table, crop moisture requirements, and levels of farm management and technology, are held constant at current levels.

The crop productivity model is also employed to estimate the impacts of alternative levels of precipitation on field crop yields. These analyses are conducted given the current and an altered thermal regime, and given identified extremes in precipitation levels (Section 2.1).

The structure of the crop productivity model used to estimate yield response of field crops to alternative climatic regimes is presented in Appendix 4. Data required for these analyses and crop yields under the alternative climatic regimes are presented in Appendices 5 and 6 respectively.

Estimates of yield levels required to obtain a positive return to investment are used in conjunction with the crop productivity estimates to screen out yields which would be insufficient to generate a profit. Threshold yield levels are estimated relative to current economic conditions and summarized in Appendix 7. These economic data are applied to the field crop yields estimated given changes in climatic long-term norms and variability in precipitation levels.

The impacts of alternative climatic regimes on the economic suitability of land resources for field crops in each region are determined by comparing estimates of the availability of each land type to yield levels which would be sufficient to generate a profit. Estimates of the current availability of land for field crop production are presented in Appendix 8. Total availability of land is held constant at current levels, and hence the analysis isolates the effects of alternative climatic regimes on the economic suitability of land in each region. The results from the analyses are presented in Appendix 9.

2.3.2 Horticultural Crops

A modified version of qualitative climatic rating schemes for individual horticultural crops developed by Brown and Place (1985) is employed to estimate the extent to which changes in long-term climatic normals might affect the production opportunities for horticultural crops throughout Ontario.

The Brown and Place rating scheme is crop specific and applicable to current climatic conditions in South Western Ontario. Application of all components of the scheme requires a considerable amount of information over a wide range of agroclimatic characteristics including spring and fall frosts, minimum winter temperatures, snow cover, maximum summer temperatures, and dry periods during the growing period. The procedures developed by Brown and Place represent a usable foundation for determining the impacts of climatic change on production opportunities for horticultural crops. In order to expand this system for application throughout the province and to consider climatic conditions that are not currently found in South Western Ontario, the

system was modified. Furthermore, it was not feasible to estimate the implications of a 2 X CO₂ atmosphere on several of the agroclimatic parameters employed by Brown and Place and hence a number of simplifications were instituted.

The generalized climatic rating scheme used in this project is presented in Table 2.3. Horticultural crops are divided into two broad categories, and corn heat units are used as the primary criterion for evaluating climatic potential for production. Sweet corn is representative of the frost-sensitive horticultural crops, and a secondary criterion, frost-free season, is used in the rating for the crop. Grapes and apples are used to represent the winter-temperature-sensitive crops. A secondary criterion of extreme winter temperatures is used in conjunction with corn heat units to judge the climatic potential for these crops.

The impacts of climatic change on production opportunities for each of the representative horticultural crops was determined by comparing the rating scheme outlined in Table 2.3 to the climatic characteristics associated with map units delineated on the Soils of Canada Map (Clayton et al., 1977) under the current and altered climatic regimes. Procedures and data used to estimate corn heat units and the frost-free¹ period for each map unit under the two climatic regimes are presented elsewhere (LEG, 1985, Section 2.2.1). Estimates for extreme winter temperatures within each map unit under each climatic regime were derived using:

- i) available information on mean monthly temperatures given the current and altered climate, and
- ii) the observed relationship between mean monthly temperature and daily extreme temperatures during the month.

The former were estimated by fitting data provided by the AES to the map units (LEG, 1985, Section 2.2.1). The latter were estimated using historical data recorded at 24 climate stations throughout Ontario. The estimated effects of a doubling in CO₂ on corn heat units, frost-free period and extreme minimum winter temperatures for each of the map units are summarized in Appendix 10. The impacts of the altered climatic regime on production opportunities for horticultural crops are presented as well. These results were used in conjunction with data on the total area of each map unit (Kirkwood et al., 1983), and the distribution of map units within the six identified regions of Ontario (LEG, 1985, Appendix 4) to determine the proportion of each region which would have a climatic potential for the production of horticultural crops under the current and altered climatic regime.

¹ For this project, growing season start and end are defined as the day when mean daily temperatures rise and fall above 5°C respectively. These dates compare favourably with the start and end of the frost-free period and therefore frost-free period and growing season are used interchangeably in this report.

TABLE 2.3: GENERALIZED CLIMATIC RATING SCHEME FOR HORTICULTURAL CROPS

FROST-SENSITIVE CROPS

REPRESENTATIVE CROP: SWEET CORN

		PRIMARY CRITERION: CORN HEAT UNITS			
		<2500	2500-2800	2800-3100	>3100
SECONDARY CRITERION:	>133	Fair	Good	Good	Very Good
FROST-FREE PERIOD (DAYS)	<133	Poor	Fair	Not Applicable	Not Applicable

WINTER-TEMPERATURE-SENSITIVE CROPS

REPRESENTATIVE CROP: GRAPES

		PRIMARY CRITERION: CORN HEAT UNITS		
		<2800	2800-3100	>3100
SECONDARY CRITERION:	-26°C or Warmer	Not Likely to be Grown	Fair	Very Good
EXTREME WINTER TEMPERATURES	-26°C to -29°C	Not Likely to be Grown	Poor	Good
	< -29°C	Not Likely to be Grown	Not Likely to be Grown	Poor

REPRESENTATIVE CROP: APPLES

		PRIMARY CRITERION: CORN HEAT UNITS				
		<1900	1900-2500	2500-2800	2800-3100	>3100
SECONDARY CRITERION:	-35°C or Warmer	Not Likely to be Grown	Fair	Good	Very Good	Very Good
EXTREME WINTER TEMPERATURES	<-35°C	Not Likely to be Grown	Poor	Fair	Good	Good

2.3.3 New Crops

A preliminary assessment of the opportunities for introducing new crops to Ontario under the altered climatic regime is based upon identifying areas in the United States where climatic conditions are presently similar to those anticipated in South Western Ontario under the altered climatic regime, and by observing present patterns of crop production in these areas. Climatic stations in Ohio, Illinois, Indiana and Maryland at latitudes ranging from 38°N to 40°N compared favourably to the estimated climatic changes for South Western Ontario (Appendix 11). Information on crop production in these states is obtained from state and federal statistical summaries.

2.4 Provincial Assessments

The province-wide assessments examine the effects of the altered climatic regime and variability in precipitation on Ontario's potential for food production. The principal tool of investigation is the Ontario land evaluation system. A linear programming model is used to integrate yield responses to climatic change for several crops in all regions of Ontario relative to other factors such as land availability for agriculture, crop production levels and agricultural land use practices which would maintain soil quality. The analyses measure the aggregate implications of alternative climatic regimes on the provincial prospects for food production, indicating the extent to which losses in productivity in one region might be offset by higher yields elsewhere. The version of the programming model employed in this project is outlined in Brklacich et al. (1984). Further information on this approach to resource assessment is presented in Smit et al. (1981).

Ontario's potential for food production is estimated under six sets of conditions or scenarios. Each of the scenarios represents an alternative climatic regime and crop yields are adjusted accordingly. The climatic regime associated with each scenario is summarized in Table 2.4.

TABLE 2.4: ALTERNATIVE CLIMATIC REGIMES EMPLOYED IN THE PROVINCE-WIDE ASSESSMENTS

	THERMAL REGIME	
	Current	Future
PRECIPITATION		
Average	Scenario 1	Scenario 2
High	Scenario 3	Scenario 5
Low	Scenario 4	Scenario 6

Procedures for estimating the characteristics of each climatic regime are described in Section 2.1. Methods for assessing crop yield response to specified sets of climatic conditions are presented in Section 2.3, and yields under each climatic regime are presented in Appendix 6. The following conditions are held constant under all scenarios.

- 1) Land available for crop production is limited to current levels (Appendix 8).
- 2) Crop production levels are set equal to current provincial levels.¹
- 3) Land use practices which will maintain or enhance soil quality are implemented.²

¹ Estimated from provincial statistics on annual production, 1976-1981 (OMAF, various dates).

² The rationale and specification of soil conserving land use practices are presented in LEG (1983).

3 EFFECTS OF A DOUBLING IN CO₂ ON AGROCLIMATIC RESOURCES IN ONTARIO

3.1 Changes in Long-Term Climatic Normals

A doubling in atmospheric concentrations of CO₂ would have considerable effects on agroclimatic resources throughout Ontario. Substantial increases in growing season length, mean daytime temperatures, corn heat units, precipitation, and potential evapotranspiration could be expected throughout the province (Table 3.1). A summary of the altered climatic regime follows.

Growing Season Length

Estimated increases in growing season length range from 49 days to 60 days (Table 3.1). The available growing period in Northern Ontario under the altered climatic regime would approach the current period in South Western Ontario. In the Central, South Central, Western and South Western regions the growing season would exceed 200 days, and be comparable to the present season in southern Illinois.

Temperature¹

A doubling in atmospheric concentrations of CO₂ implies a considerable increase in mean daytime temperatures during the growing season throughout Ontario (Table 3.1). Temperatures in Northern Ontario would be in the order of 17°C, or higher than the current norm in South Western Ontario. In other regions, the mean daytime temperature would exceed 18°C. It is estimated that the altered climatic regime would tend to reduce the temperature gradient from south to north from the present 1.6°C to 1.4°C.

Corn Heat Units¹

The longer growing season and higher temperatures would have a considerable effect on available corn heat units in each region of the province (Table 3.1). Accumulated corn heat units for the extended growing period in Northern Ontario would be similar to present conditions in the current agricultural heartland of South Western Ontario. Increases in corn heat units of approximately 50 per cent could be expected in all other regions under the future climate.

Precipitation¹

An enriched CO₂ environment implies considerable increases in precipitation levels during the growing season for all regions of Ontario (Table 3.1). Regional levels of precipitation under the altered climatic regime would exceed current norms experienced anywhere in the province, and the province-wide range in precipitation would increase from 80 mm to about 90 mm.

¹ Mean daytime temperature, corn heat units, precipitation and potential evapotranspiration are for the growing season.

TABLE 3.1: ESTIMATED IMPACTS OF 2 X CO₂ ON SELECTED CLIMATIC NORMALS

CLIMATIC PARAMETER	REGION ¹	CURRENT NORM	ESTIMATED CHANGE	
			Absolute	%
Growing Season	NO	115	49	42
Length (Days)	EO	138	49	36
	CO	146	59	41
	SCO	152	60	40
	WO	154	57	37
	SWO	166	57	34
Mean Daytime	NO	15.2	1.9	12
Temperature ² (°C)	EO	16.4	1.9	11
	CO	16.7	1.5	9
	SCO	16.7	1.5	9
	WO	16.4	1.7	11
	SWO	16.8	1.7	10
Corn Heat Units ²	NO	2.0	1.3	61
(000's)	EO	2.7	1.4	51
	CO	2.9	1.5	52
	SCO	3.0	1.6	51
	WO	3.0	1.5	51
	SWO	3.3	1.6	47
Precipitation ² (mm)	NO	325	135	42
	EO	385	104	27
	CO	360	150	42
	SCO	378	150	40
	WO	390	139	36
	SWO	406	144	36
Potential Evapo-	NO	432	230	65
transpiration ² (mm)	EO	481	244	58
	CO	454	269	58
	SCO	457	271	56
	WO	476	270	56
	SWO	491	278	54

¹ NO = Northern Ontario
EO = Eastern Ontario
CO = Central Ontario

SCO = South Central Ontario
WO = Western Ontario
SWO = South Western Ontario

² Mean daytime temperature, corn heat units, precipitation and potential evapotranspiration are for the growing season..

Potential Evapotranspiration¹

An altered climate characterized by longer growing periods and higher temperatures would, not surprisingly, also imply marked increases in potential evapotranspiration (Table 3.1). Expected increases would range from approximately 230 mm to 280 mm, with the lowest increases in Northern and Eastern Ontario.

3.2 Changes in Variability in Growing Season Precipitation

The combination of expected increases in precipitation and a longer growing season would be expected to result in substantial increases in average levels of total precipitation during the cropping season (Table 3.1). The altered climatic regime would also be characterized by a considerable increase in the distribution of yearly levels of precipitation around the future norms (Table 3.2). Actual low or high precipitation levels that would be expected in any particular year would be greater than current lows and highs, but the range between these extremes would be expected to increase sharply in the future. While an enriched CO₂ environment implies increases in precipitation, it could also imply considerable increases in the variability of precipitation levels from year to year.

¹ Mean daytime temperature, corn heat units, precipitation and potential evapotranspiration are for the growing season.

TABLE 3.2: CHANGES IN VARIABILITY IN GROWING SEASON PRECIPITATION UNDER AN ALTERED CLIMATIC REGIME

REGION	CLIMATIC REGIME	PRECIPITATION (mm)			
		Low	Average	High	Range
Northern Ontario	Current	218	325	432	214
	Future	340	460	635	295
Eastern Ontario	Current	296	385	481	185
	Future	371	489	606	235
Central Ontario	Current	277	360	454	177
	Future	393	510	576	183
South Central Ontario	Current	268	378	457	189
	Future	354	528	639	285
Western Ontario	Current	277	390	476	199
	Future	354	529	640	286
South Western Ontario	Current	284	406	491	207
	Future	374	550	666	292

4 EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON CROP PRODUCTION AND ECONOMIC OPPORTUNITIES AT THE FARM LEVEL

A cash grain farm model (Pfeiffer, 1976) is employed to estimate the effects of climatic change on farm profits and on the optimal allocation of available resources. The analyses are conducted for a "typical" 200 hectare cash grain farm in South Western Ontario and the model is run under two scenarios: current climatic norms and expected increases in these norms stemming from an enriched CO₂ environment. Crop yields are adjusted to reflect the impacts of these climatic changes, while all other conditions such as production technologies, production costs and crop prices are maintained at constant levels approximating conditions during 1977-1978. Hence, the model isolates the extent to which climatic change would affect profitability and optimal patterns of crop production on this "typical" farm enterprise .

The degree to which variability in precipitation levels implies a risk to crop production and farm profits is also assessed. These analyses are conducted assuming decisions regarding the operation of the "typical" cash grain farm in South Western Ontario are based upon prevailing economic conditions and long-term climatic normals, and assuming the variations in precipitation outlined in Section 3.2. Grain yields are adjusted to reflect alternative levels for precipitation. This provides a basis for judging the combined effects of climatic change and variability on total crop production, value of crop production and profitability.

4.1 Changes in Long-Term Climatic Normals

Given the specified economic conditions and current climatic normals for South Western Ontario, the maximum net profit feasible for this "typical" cash grain farm is estimated at \$22,000 per year (Table 4.1). This profit level would only be feasible given the full utilization of all available land resources, and by planting 134 hectares to grain corn, 58 hectares to soybeans and 10 hectares to winter wheat. Total sales of crop products would generate almost \$122,000 of gross income.

Maximum profit levels and the optimal allocation of available resources would be expected to change considerably given the specified changes in long-term climatic normals for the region (Table 4.1). Maximum net returns could increase to \$27,000 per year, or by 24 per cent. Attaining these profit levels would require a further reliance upon grain corn production. Once again, all available land resources would be required, with 187 hectares devoted to grain corn and 15 hectares to winter wheat. The inclusion of soybeans in the production mix would reduce the profit margin. Income from the sales of grain corn and winter wheat would approach \$130,000. The vulnerability of monoculture farming to market fluctuations and to pests and diseases, as well as the potential impacts of continuous cropping on land quality, raises questions regarding the long-term sustainability of such a farm enterprise.

TABLE 4.1: EFFECTS OF CHANGES IN LONG-TERM CLIMATIC NORMALS ON CROP PRODUCTION AND ECONOMIC OPPORTUNITIES AT THE FARM LEVEL

RESOURCE USE AND PRODUCTION

	Land Use (ha) Given:		Production (tonnes) Given:	
	Current Norms	Future Norms	Current Norms	Future Norms
Grain Corn	134	187	892	1264
Soybeans	58	0	141	0
Winter Wheat	10	15	35	45
Total	202	202	-	-

ECONOMIC IMPLICATIONS

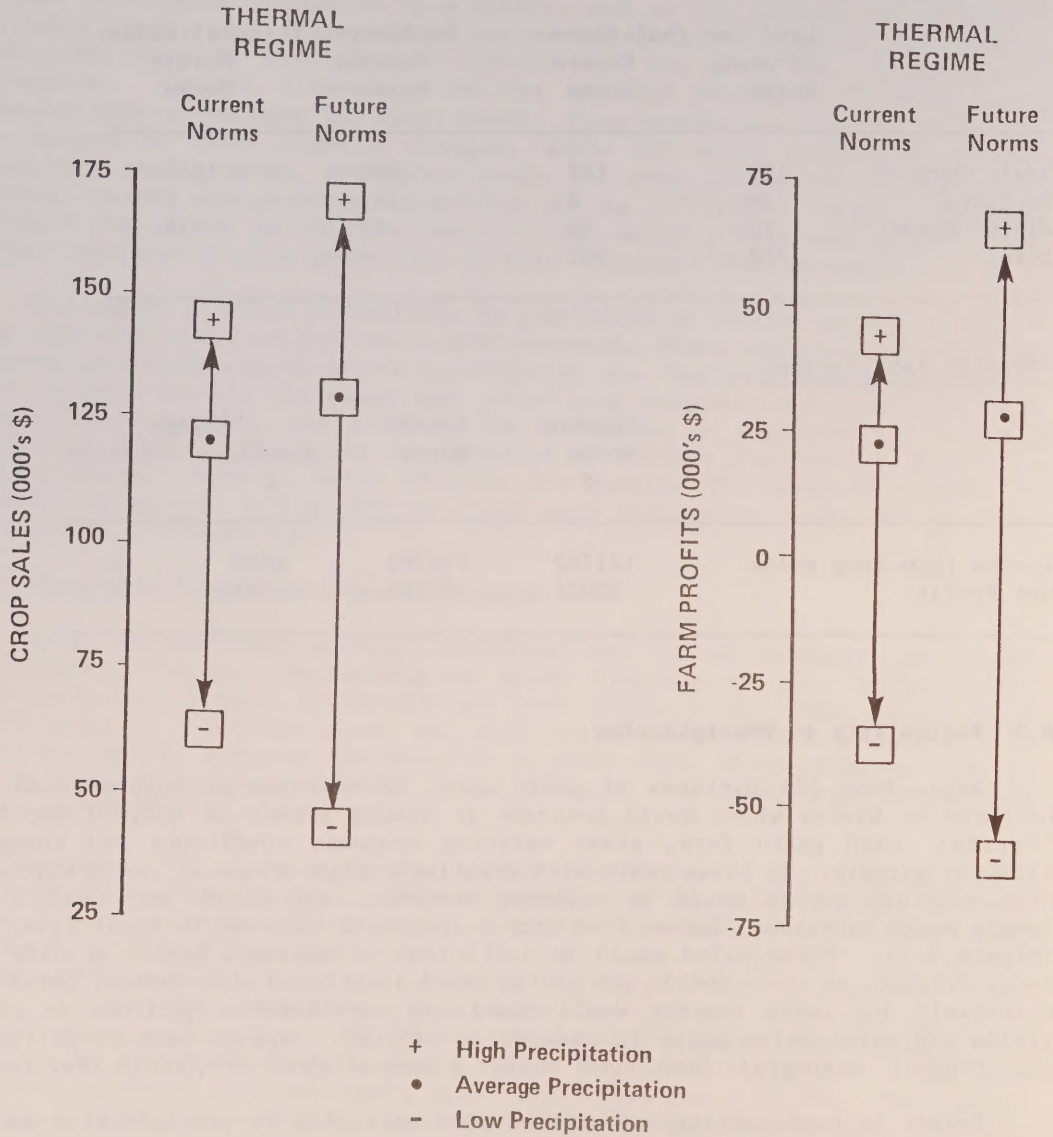
	Current Norms	Future Norms	Change	
	\$	\$	Absolute \$	Relative %
Income from crop sales	121702	129782	8080	6
Net Profit	22024	27207	5183	24

4.2 Variability in Precipitation

Sales from 134 hectares of grain corn, 58 hectares of soybeans and 10 hectares of winter wheat would generate an annual profit of \$22,000 for the "typical" cash grain farm, given existing economic conditions and current climatic normals. In those years with relatively high levels of precipitation, crop moisture stress would be relieved somewhat, and yields and production levels would increase. Income from crop sales would increase to about \$144,000 (Figure 4.1). These sales would be sufficient to increase annual profits to about \$45,000, or about double the profit level associated with current normals. Relatively dry years however would result in considerable declines in crop yields and total sales would be reduced to \$65,000. Under these conditions, the "typical" cash grain farm would suffer a loss of about \$34,000 in that year.

Trends in profitability associated with variation in precipitation would tend to be the same under an enriched CO₂ environment, but the effects of a relatively dry or wet year on farm profits would be more pronounced (Figure 4.1). Crop sales and farm profits are estimated at \$130,000 and \$27,000 respectively, given changes in long-term climatic norms, ceteris paribus. Higher levels of precipitation would reduce crop moisture stress and thereby increase yields. Total crop sales would generate an income of \$168,000, and an annual profit of more than \$65,000 would be realized. Relative to

FIGURE 4.1: VARIABILITY IN PRECIPITATION AND ITS IMPACTS ON CROP PRODUCTION AND ECONOMIC OPPORTUNITIES AT THE FARM LEVEL



profit levels associated with changes in long-term normals, this represents an increase of some 140 per cent. In the driest years however moisture stress would result in drastic reductions in crop yields and total income from crop sales would be reduced to \$43,000. Farm losses would approach \$60,000 for the year. Overall, fluctuations in annual farm profits stemming from precipitation extremes would be expected to increase under the altered climatic regime. This instability could trigger additional problems at the farm level including inadequate cash flow and increases in debt load.

4.3 Concluding Comment

This section outlines an approach for assessing farm level impacts of climatic change. The analyses have been conducted for one type of farming in one region of Ontario, and isolate the impacts of climatic change on optimal use of resources and on-farm profits. Other conditions such as production costs, crop prices and crop production opportunities in one region relative to another are held constant. The approach employed in this section could be expanded to consider other types of farming over a wider area and alternative economic conditions. While these extensions would indicate which types of farming would and would not be sensitive to specified changes in climate and other conditions, the basic approach is not intended to assess the broader issue of the effects of climatic change on regional opportunities for agricultural production. Assessing these issues would require additional information, including yield responses to climatic change for a wide range of crops on different types of land in each region, and estimates of the availability of land resources for agriculture.

5 EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON REGIONAL OPPORTUNITIES FOR CROP PRODUCTION

This section assesses the extent to which climatic change and variations in precipitation levels might affect the long-term opportunities for crop production in each of six regions throughout Ontario. The section is divided into three parts. Initially the effects of a CO₂-induced climatic change and variability in precipitation levels on the biophysical and economic prospects for common field crops in Ontario are appraised. Then the implications of changes in long-term climatic normals on the production opportunities for horticultural crops are assessed. The section concludes with comments on introducing new crops to Ontario under the altered climatic regime.

5.1 Effects on Production Opportunities for Field Crops

5.1.1 Grain Corn

Changes in Long-Term Climatic Normals¹

The specified changes in long-term climatic norms would have considerable impacts on grain corn yields throughout Ontario (Table 5.1). The most profound effect would be in Northern Ontario where it is not presently feasible to produce the crop. Yields would increase to such an extent that it would be feasible to obtain a high return to investment on well-drained loamy soils (land types A and G) and on lands that have a low drought tolerance (land types B and C). Yields on lands where limitations imposed by excessive moisture conditions have been overcome (land type D) would be sufficient to obtain a modest return.

In Eastern Ontario, where current yields for grain corn are not sufficient to generate a high return on any land type, high returns to investment would be expected on land types A, D and G under the climatic change scenario. Furthermore, the specified changes in climatic norms would increase yields on land type C to such a degree that it would be feasible to obtain at least a modest return. The effects of the specified changes in climatic conditions on the outlook for corn production in Central Ontario are similar to the expected adjustments in Eastern Ontario.

In the Western and South Central Ontario regions the economic potential for the production of grain corn on lands where it is currently feasible to reap a profit would either be enhanced or unaffected by the specified changes in climate. On lands which are prone to droughtiness (land types B and C)

¹ The analysis in Section 5.1 isolates the effects of an altered climatic regime on crop yields. There is evidence that while increases in CO₂ would benefit crops by increasing the efficiency of photosynthesis and water use, the moisture stress associated with warmer summers in a 2 X CO₂ environment would more than offset any benefits (Waggoner, 1983). While the results in this report could overestimate the absolute change that would be expected in a CO₂ enriched environment, the direction and magnitude of the estimated changes are appropriate.

TABLE 5.1: EFFECTS OF CHANGES IN LONG-TERM CLIMATIC NORMALS ON GRAIN CORN YIELDS

Region	Land Type	Area 000's ha	Current FAY ¹ t/ha	Change from Current t/ha	%
NO	A,G	134	0.0	+9.1 **	-
	B	41	0.0	+6.8 **	-
	C	36	0.0	+7.0 **	-
	D	24	0.0	+5.7 *	-
	E	77	0.0	+2.7	-
EO	A,G	179	5.4 *	+3.4 **	62.2
	B	81	3.5	+1.7	48.0
	C	173	3.8	+1.9 *	49.9
	D	45	3.7	+3.6 **	98.5
	E	256	1.8	+2.3	126.8
CO	A,G	170	6.6 **	+1.5 **	23.0
	B	22	4.6	0.0	- 0.2
	C	55	5.0	+0.2 *	3.1
	D	12	4.3	+2.9 **	66.8
	E	19	2.0	+2.2	106.8
SCO	A,G	429	6.9 **	-0.2 **	- 2.7
	B	37	4.0	-0.8	-19.5
	C	44	4.1	-0.7	-18.0
	D	2	5.9 *	+1.0 **	17.0
	E	16	3.4	+0.9	27.2
WO	A,G	785	6.9 **	+0.2 **	2.8
	B	64	4.1	-0.5	-12.7
	C	98	4.4	-0.5	-10.2
	D	40	5.4 *	+1.4 **	26.4
	E	96	2.8	+1.4	50.5
SWO	A,G	929	7.3 **	-1.2 *	-16.9
	B	166	4.2	-1.4	-34.5
	C	155	4.2	-1.4	-34.3
	D	338	6.4 **	+0.4 **	6.1
	E	140	3.7	+0.6	15.3

¹ Farm Attainable Yields (Dry Weight).

* Yields sufficient for a modest return to investment given current economic conditions.

** Yields sufficient for a high return to investment given current economic conditions.

No asterisk indicates yields would be insufficient to generate a profit over the long-term.

however the climatic change scenario would lead to an increase in moisture stress with a concomitant decline in grain corn yields.

The economic potential for grain corn production in South Western Ontario would suffer under the specified climatic changes. On lands which are well to excessively well-drained (land types A, B, C and G) moisture stress would increase to such an extent that yields for grain corn would decrease by an appreciable amount. On land types A and G, these yield losses would reduce the profit margin to the modest return category. Yields on lands with excessive moisture (land types D and E) would be expected to increase under the altered climatic regime, but the profitability of grain corn production would not be affected by these changes.

Variability in Precipitation and Risks to Production

The risks to production associated with fluctuations in precipitation would vary from region to region and from land type to land type (Figure 5.1 and Table 5.2).¹ In Northern Ontario, where the future thermal regime would be amenable to grain corn production, precipitation extremes would contribute to considerable fluctuations in crop yields (Figure 5.1). On well-drained lands in the region, high and low levels of precipitation would reduce crop yields and profit margins. High returns to investment would be feasible on excessively well-drained lands in those years with high levels of precipitation, but these lands would be economically unsuitable for grain corn production during the droughty years. The opposite would be expected on lands with excessive moisture for grain corn production. Crop yields in the drier years would be modestly greater than yields given average levels of precipitation, and relatively wet conditions would eliminate the opportunities for grain corn production. Overall, it is estimated that on average about 69 per cent of Northern Ontario's land base would be economically suitable for the production of grain corn (Table 5.2). Relatively wet years would have little impact on the regional potential. In the driest years, however, land in Northern Ontario on which it would be profitable to produce grain corn would be confined to about 46 per cent of the regional agricultural land supply.

Under current conditions in Eastern Ontario, yearly fluctuations in total precipitation for the growing season have a modest impact on grain corn yields, and the economic opportunities for the production of this crop are quite limited (Figure 5.1). The specified changes in temperature would enhance the opportunities for grain corn in this region, but variability in precipitation would represent a substantial threat to production. Under the changed regime, a modest to high return to investment would be feasible given average to high levels of precipitation on the well to excessively well-drained lands. Relatively dry conditions however would probably lead to crop failure on lands susceptible to droughty conditions (land types B and C). On lands which are imperfectly to poorly drained, crop moisture stress would be greater in the wetter years than in those years with average or low precipitation levels.

¹ The impacts of an altered climate and variations in precipitation on grain corn yields are presented for selected regions in this section. Results from the analyses for all regions are summarized in Appendices 6 and 9.

FIGURE 5.1: REGIONAL EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON YIELDS FOR GRAIN CORN

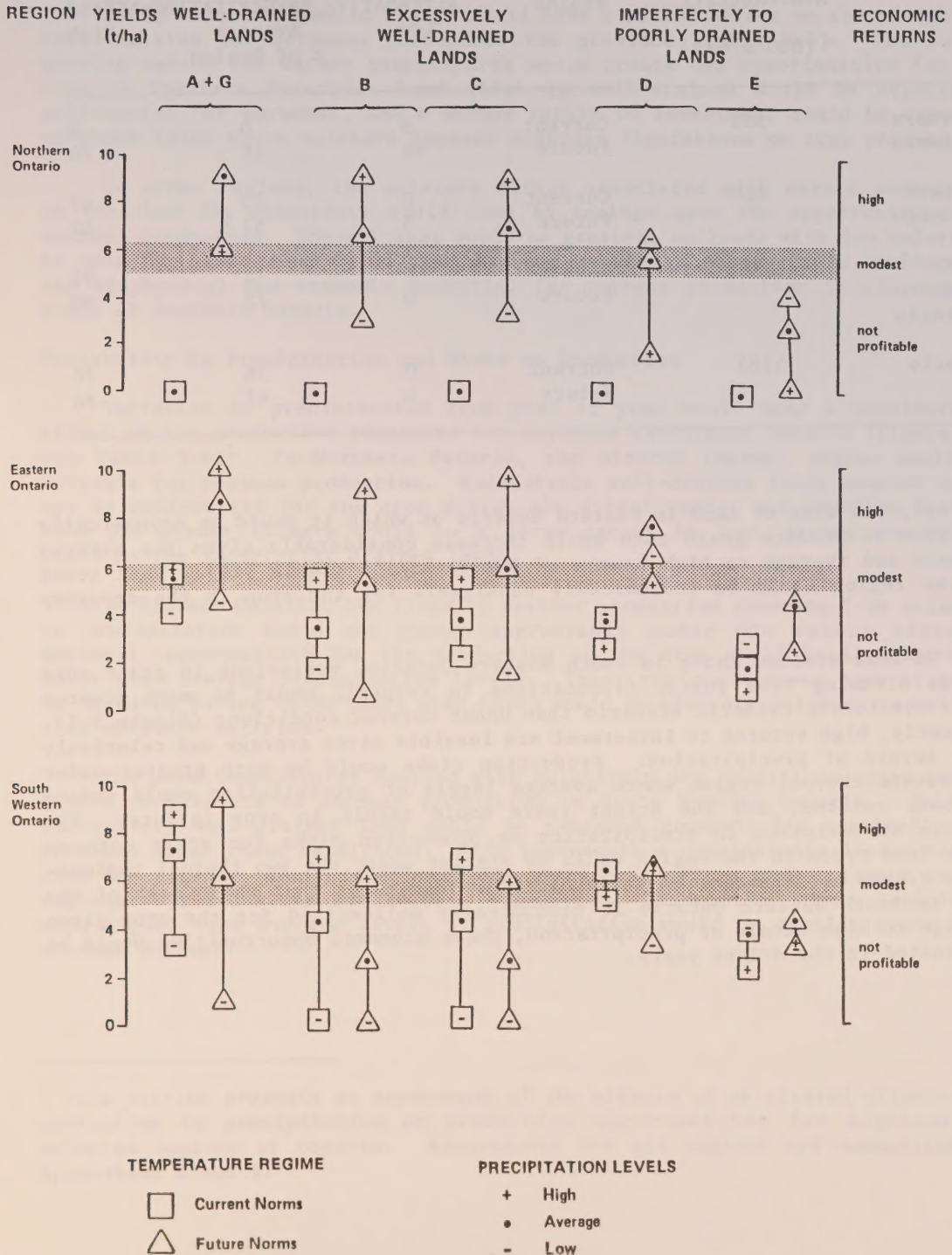


TABLE 5.2: EFFECTS OF CLIMATIC CHANGE AND ALTERNATIVE PRECIPITATION LEVELS ON THE ECONOMIC SUITABILITY OF LAND FOR GRAIN CORN

REGION	LAND AVAILABILITY (000's ha)	CLIMATIC REGIME	ECONOMIC SUITABILITY GIVEN ALTERNATIVE PRECIPITATION LEVELS		
			Low	Average % of Region	High
Northern Ontario	343	Current	0	0	0
		Future	46	69	70
Eastern Ontario	920	Current	0	20	47
		Future	5	52	67
South Western Ontario	1761	Current	0	72	92
		Future	0	72	90
Ontario	5183	Current	0	56	78
		Future	4	67	86

Overall, the area of land in Eastern Ontario on which it would be economically feasible to produce grain corn would increase considerably given the altered climate and average to high levels of precipitation (Table 5.2). Vast areas in the region would be economically unsuitable for the crop in the droughty years.

On well-drained lands in South Western Ontario, variations in grain corn yields stemming from yearly fluctuations in rainfall would be much greater under the future climatic scenario than under current conditions (Figure 5.1). Currently, high returns to investment are feasible given average and relatively high levels of precipitation. Production risks would be much greater under the future thermal regime where average levels of precipitation would reduce economic returns, and the driest years would result in crop failure. The effects of variation in precipitation on production risks for grain corn on other land types in the region would be similar under the two thermal regimes. These trends are apparent in Table 5.2 which indicates that while most of the land in South Western Ontario is economically well-suited for the crop given average to high levels of precipitation, these economic opportunities would be eliminated in the driest years.

5.1.2 Soybeans

Changes in Long-Term Climatic Norms

A CO₂-induced climatic change would have a marked effect on the production opportunities for soybeans throughout the province (Table 5.3). The longer growing season and warmer temperatures would create new opportunities for the crop in Northern Ontario. Land which is well-drained would be especially well-suited for soybeans, and a modest return to investment could be expected on those lands where moisture imposes moderate limitations on crop production.

In other regions, the moisture stress associated with warmer summers in an enriched CO₂ atmosphere would tend to impinge upon the opportunities for soybean production. These losses would be greatest on lands with low tolerance to droughty conditions (land type B), and result in considerable declines in the biophysical and economic potential for soybean production in all regions south of Northern Ontario.

Variability in Precipitation and Risks to Production

Variation in precipitation from year to year would have a considerable effect on the production prospects for soybeans throughout Ontario (Figure 5.2 and Table 5.4)¹ In Northern Ontario, the altered thermal regime would be suitable for soybean production. Excessively well-drained lands however would not be well-suited for the crop during the driest years, and benefits derived from the warmer climate would to a large extent be lost during the wetter years on the imperfectly drained lands.

In Eastern Ontario, the risks to soybean production stemming from extremes in precipitation would not change appreciably under the future climate. Regional opportunities for the production of the crop would be diminished by lower than average precipitation levels. These regional losses however could be recouped during those years when there would be adequate moisture to relieve crop moisture deficits.

The warm temperatures coupled with relatively dry conditions would impose severe constraints on soybean production in South Western Ontario. Well to excessively well-drained land would be rendered economically unsuitable for soybeans under these conditions. This represents a considerable deterioration from the present, where relatively dry years have only a modest impact on the regional opportunities for soybean production. Production risks associated with higher than average levels of precipitation would be similar under both thermal regimes.

¹ This section presents an assessment of the effects of an altered climate and variations in precipitation on production opportunities for soybeans in selected regions of Ontario. Assessments for all regions are summarized in Appendices 6 and 9.

TABLE 5.3: EFFECTS OF CHANGES IN LONG-TERM CLIMATIC NORMALS ON SOYBEAN YIELDS

Region	Land Type	Area 000's ha	Current FAY ¹ t/ha	Change from Current t/ha	%
NO	A,G	134	0.0	+2.4 **	-
	B	41	0.0	+1.7 *	-
	C	36	0.0	0.0	-
	D	24	0.0	+1.6 *	-
	E	77	0.0	+0.8	-
EO	A,G	179	1.9 *	-0.1 *	- 3.1
	B	81	1.4 *	-0.3	-21.4
	C	173	0.0	0.0	-
	D	45	1.2 *	+0.4 *	29.6
	E	256	0.6	+0.3	52.6
CO	A,G	170	2.1 **	-0.3 *	-15.6
	B	22	1.3 *	-0.3	-25.8
	C	55	0.0	0.0	-
	D	12	1.5 *	0.0 *	0.0
	E	19	0.8	+0.1	18.7
SCO	A,G	429	1.9 *	-0.2 *	- 8.8
	B	37	1.2 *	-0.2	-16.0
	C	44	0.0	0.0	-
	D	2	1.5 *	0.0 *	2.8
	E	16	0.8	+0.1	14.5
WO	A,G	785	2.3 **	-0.6 *	-23.5
	B	64	1.5 *	-0.5	-31.3
	C	98	0.0	0.0	-
	D	40	1.8 *	-0.2 *	-12.4
	E	96	0.9	0.0	0.4
SWO	A,G	929	2.2 **	-0.5 *	-23.6
	B	166	1.3 *	-0.4	-27.9
	C	155	0.0	0.0	-
	D	338	1.8 *	-0.3 *	-16.8
	E	140	1.0	-0.1	-10.4

¹ Farm Attainable Yields (Dry Weight).

* Yields sufficient for a modest return to investment given current economic conditions.

** Yields sufficient for a high return to investment given current economic conditions.

No asterisk indicates yields would be insufficient to generate a profit over the long-term.

FIGURE 5.2: REGIONAL EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON YIELDS FOR SOYBEANS

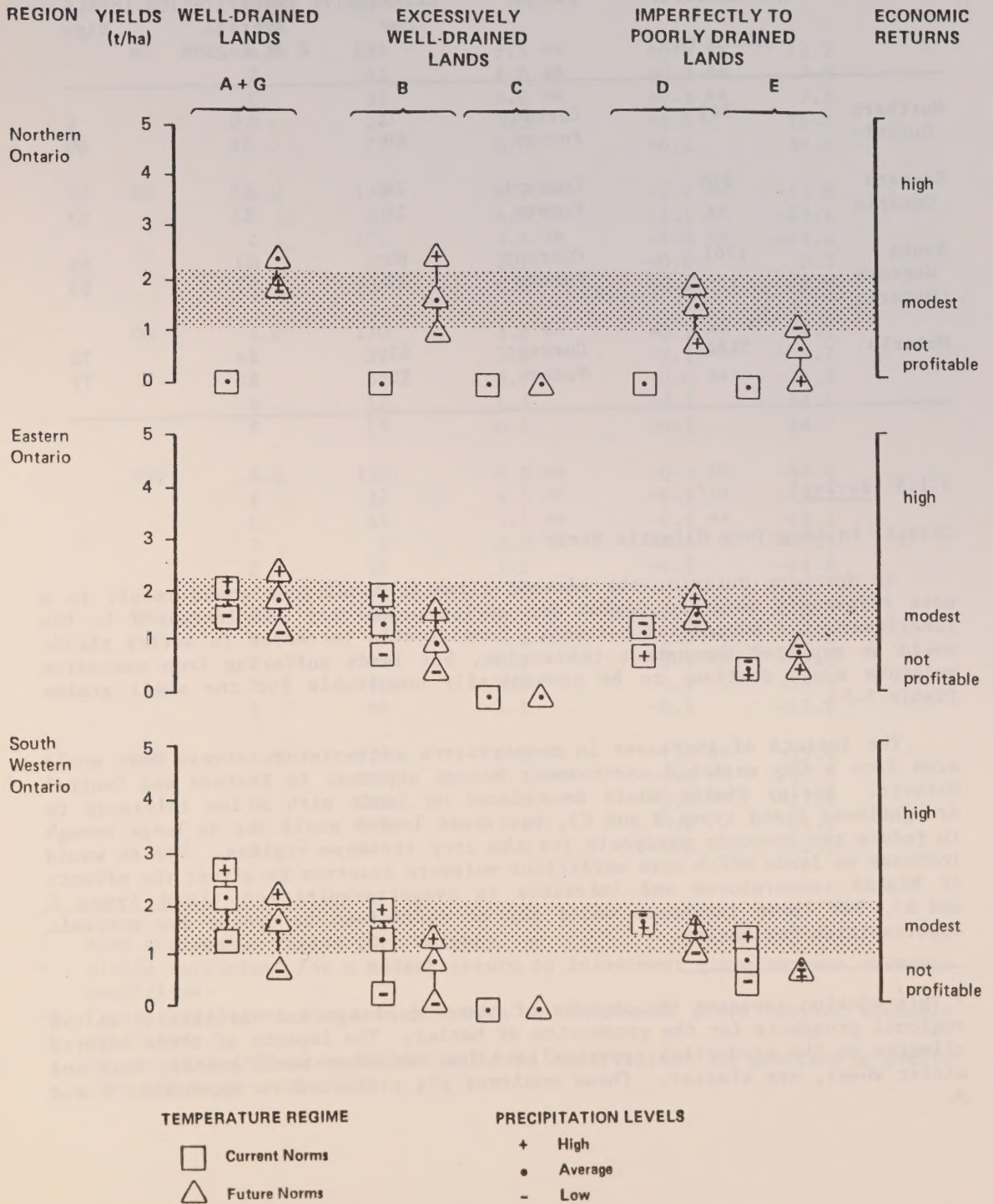


TABLE 5.4: EFFECTS OF CLIMATIC CHANGE AND ALTERNATIVE PRECIPITATION LEVELS ON THE ECONOMIC SUITABILITY OF LAND FOR SOYBEANS

REGION	LAND AVAILABILITY (000's ha)	CLIMATIC REGIME	ECONOMIC SUITABILITY GIVEN ALTERNATIVE PRECIPITATION LEVELS		
			Low	Average % of Region	High
Northern Ontario	343	Current	0	0	0
		Future	69	58	60
Eastern Ontario	920	Current	24	33	48
		Future	24	33	53
South Western Ontario	1761	Current	80	81	83
		Future	19	72	83
Ontario	5183	Current	61	64	72
		Future	20	62	77

5.1.3 Barley¹

Changes in Long-Term Climatic Norms

In Northern Ontario, the altered climatic conditions would result in a more favourable moisture regime for barley production and increases in the likelihood of a successful harvest. Considerable increases in barley yields could be expected throughout the region, but lands suffering from excessive moisture would continue to be economically unsuitable for the small grains (Table 5.5).

The impacts of increases in temperatures and moisture stress that would stem from a CO₂ enriched environment become apparent in Eastern and Central Ontario. Barley yields would be reduced on lands with a low tolerance to droughtiness (land types B and C), but these losses would not be large enough to reduce the economic prospects for the crop in these regions. Yields would increase on lands which have sufficient moisture reserves to offset the effects of higher temperatures and increases in evapotranspiration (land types D and E), but these increases would not be sufficient to create new economic opportunities for barley.

¹ This section assesses the impacts of climatic change and variability on the regional prospects for the production of barley. The impacts of these altered climates on the production opportunities for two other small grains, oats and winter wheat, are similar. These analyses are presented in Appendices 6 and 9.

TABLE 5.5: EFFECTS OF CHANGES IN LONG-TERM CLIMATIC NORMALS ON BARLEY YIELDS

Region	Land Type	Area 000's ha	Current FAY ¹ t/ha	Change from Current t/ha	%
NO	A,G	134	3.5 **	+0.6 **	17.2
	B	41	4.0 **	+0.3 **	7.5
	C	36	4.0 **	+0.3 **	7.5
	D	24	1.5	+0.4	24.1
	E	77	0.6	+0.2	34.4
EO	A,G	179	4.7 **	-0.6 **	-12.9
	B	81	4.9 **	-1.1 **	-23.1
	C	173	4.9 **	-1.0 **	-19.6
	D	45	2.1	+0.0	0.3
	E	256	0.9	+0.1	8.6
CO	A,G	170	3.8 **	+0.2 **	4.1
	B	22	3.6 **	-0.1 **	- 3.7
	C	55	3.7 **	+0.0 **	- 0.8
	D	12	1.9	+0.3	16.1
	E	19	0.9	+0.2	18.7
SCO	A,G	429	4.9 **	-0.9 **	-18.4
	B	37	4.5 **	-0.9 **	-19.3
	C	44	4.6 **	-0.9 **	-19.1
	D	2	2.5	-0.4	-17.3
	E	16	1.1	-0.2	-16.8
WO	A,G	785	4.9 **	-0.9 **	-18.2
	B	64	4.6 **	-1.0 **	-20.8
	C	98	4.7 **	-0.9 **	-19.9
	D	40	2.4	-0.4	-14.7
	E	96	1.1	-0.1	-13.2
SWO	A,G	929	4.9 **	-1.0 **	-19.5
	B	166	4.5 **	-0.8 **	-17.7
	C	155	4.5 **	-0.8 **	-17.8
	D	338	2.6	-0.6	-21.7
	E	140	1.2	-0.3	-22.6

¹ Farm Attainable Yields (Dry Weight).

* Yields sufficient for a modest return to investment given current economic conditions.

** Yields sufficient for a high return to investment given current economic conditions.

No asterisk indicates yields would be insufficient to generate a profit over the long-term.

In the South Central, Western and South Western Ontario regions, crop moisture stress stemming from elevated CO₂ levels would be very pronounced and yield reductions for barley would be in the order of 20 per cent across these regions. Relative to existing economic conditions however these declines would not precipitate a loss in economic opportunities for barley production in these three regions.

Variability in Precipitation and Risks to Production

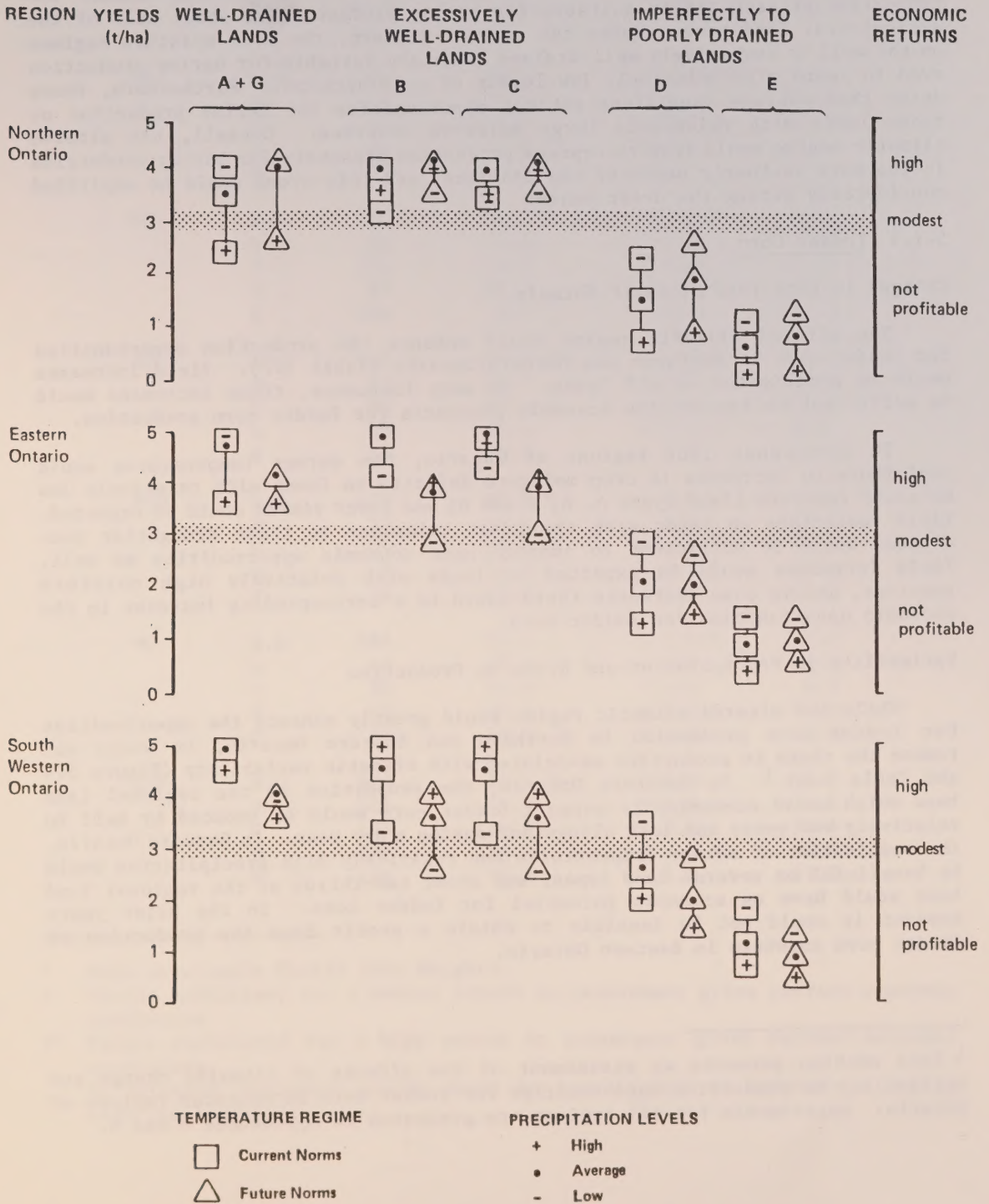
The extent to which annual variations in precipitation affect the production opportunities for barley in Northern Ontario would not be appreciably different under the alternative climatic regime (Figure 5.3 and Table 5.6).¹ The proportion of the regional land base that would be economically suitable for the crop would certainly vary given low, average and high levels of precipitation, but the effects of a particular level of precipitation is similar under the current and altered climates. Clearly, the changes in climatic norms and variability considered in this project would neither reduce nor increase the risks to barley production in Northern Ontario.

TABLE 5.6: EFFECTS OF CLIMATIC CHANGE AND ALTERNATIVE PRECIPITATION LEVELS ON THE ECONOMIC SUITABILITY OF LAND FOR BARLEY

REGION	LAND AVAILABILITY (000's ha)	CLIMATIC REGIME	ECONOMIC SUITABILITY GIVEN ALTERNATIVE PRECIPITATION LEVELS		
			Low	Average % of Region	High
Northern Ontario	343	Current	70	61	31
		Future	70	61	31
Eastern Ontario	920	Current	72	47	67
		Future	47	47	67
South Western Ontario	1761	Current	90	71	73
		Future	53	71	73
Ontario	5183	Current	84	69	77
		Future	59	69	77

¹ This section presents an assessment of the effects of an altered climate and variations in precipitation on production opportunities for barley in selected regions of Ontario. Assessments for all regions are summarized in Appendices 6 and 9.

FIGURE 5.3: REGIONAL EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON YIELDS FOR BARLEY



In Eastern and South Western Ontario however the specified ranges in precipitation levels would in all likelihood imply increases in the risk for barley production (Figure 5.3 and Table 5.6). Relatively low levels of precipitation coupled with longer and drier summers would effectively reduce the proportion of each region suitable for barley production to about half of the agricultural land base. Under the current climate, the soil moisture regimes on the well to excessively well-drained lands are suitable for barley production even in years with relatively low levels of precipitation. Furthermore, these drier than average conditions enhance opportunities for barley production on those lands with relatively large moisture reserves. Overall, the altered climatic regime would tend to depress production prospects for barley production in the more southerly parts of the province, and this trend would be amplified considerably during the drier years.

5.1.4 Fodder Corn

Changes in Long-Term Climatic Normals

The altered climatic regime would enhance the production opportunities for fodder corn in Northern and Eastern Ontario (Table 5.7). Yield increases would be anticipated on all lands. In many instances, these increases would be sufficient to improve the economic prospects for fodder corn production.

In the other four regions of Ontario, the warmer temperatures would contribute to increases in crop moisture deficits on lands with relatively low moisture reserves (land types A, B, C and G) and lower yields could be expected. Yield reductions on lands with the least tolerance to these droughtier conditions would be sufficient to impinge upon economic opportunities as well. Yield increases would be expected on lands with relatively high moisture reserves, and in some instances there would be a corresponding increase in the economic opportunities for fodder corn.

Variability in Precipitation and Risks to Production

While the altered climatic regime would greatly enhance the opportunities for fodder corn production in Northern and Eastern Ontario, it would not remove the risks to production associated with climatic variability (Figure 5.4 and Table 5.8).¹ In Northern Ontario, the proportion of the regional land base which could economically support fodder corn would be reduced by half in relatively wet years and lost altogether during a dry year. In Eastern Ontario, the combination of warmer temperatures and relatively high precipitation would be beneficial on several land types, and about two-thirds of the regional land base would have an economic potential for fodder corn. In the drier years however it would not be feasible to obtain a profit from the production of fodder corn anywhere in Eastern Ontario.

¹ This section presents an assessment of the effects of climatic change and variability on production opportunities for fodder corn in selected regions of Ontario. Assessments for all regions are presented in Appendices 6 and 9.

TABLE 5.7: EFFECTS OF CHANGES IN LONG-TERM CLIMATIC NORMALS ON FODDER CORN YIELDS

Region	Land Type	Area 000's ha	Current FAY ¹ t/ha	Change from Current t/ha	%
NO	A,G	134	18.0	+17.5 **	96.9
	B	41	13.0	+13.3 *	102.4
	C	36	13.4	+13.7 *	102.2
	D	24	11.5	+10.4	90.3
	E	77	5.5	+ 4.9	88.2
EO	A,G	179	26.7 *	+ 7.2 **	26.9
	B	81	17.4	+ 2.7	15.8
	C	173	18.9	+ 3.3	17.3
	D	45	18.3	+10.1 *	55.3
	E	256	8.9	+ 6.9	77.4
CO	A,G	170	33.9 **	- 2.5 **	- 7.4
	B	22	23.7	- 5.9	-24.9
	C	55	26.0 *	- 5.8	-22.4
	D	12	22.2	+ 5.7 *	25.6
	E	19	10.5	+ 5.9	55.7
SCO	A,G	429	27.9 *	- 2.0 *	- 7.3
	B	37	16.1	- 3.8	-23.4
	C	44	16.6	- 3.7	-21.9
	D	2	24.2	+ 2.8 *	11.5
	E	16	13.9	+ 3.0	21.2
WO	A,G	785	25.5	+ 1.8 *	7.2
	B	64	15.4	- 1.4	- 8.9
	C	98	16.5	- 1.0	- 6.3
	D	40	20.2	+ 6.4 *	31.8
	E	96	10.6	+ 6.0	56.9
SWO	A,G	929	28.5 *	- 4.8	-16.9
	B	166	16.1	- 5.6	-34.5
	C	155	16.2	- 5.6	-34.3
	D	338	24.7	+ 1.5 *	6.1
	E	140	14.2	+ 2.2	15.3

¹ Farm Attainable Yields (Dry Weight).

* Yields sufficient for a modest return to investment given current economic conditions.

** Yields sufficient for a high return to investment given current economic conditions.

No asterisk indicates yields would be insufficient to generate a profit over the long-term.

FIGURE 5.4: REGIONAL EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON YIELDS FOR FODDER CORN

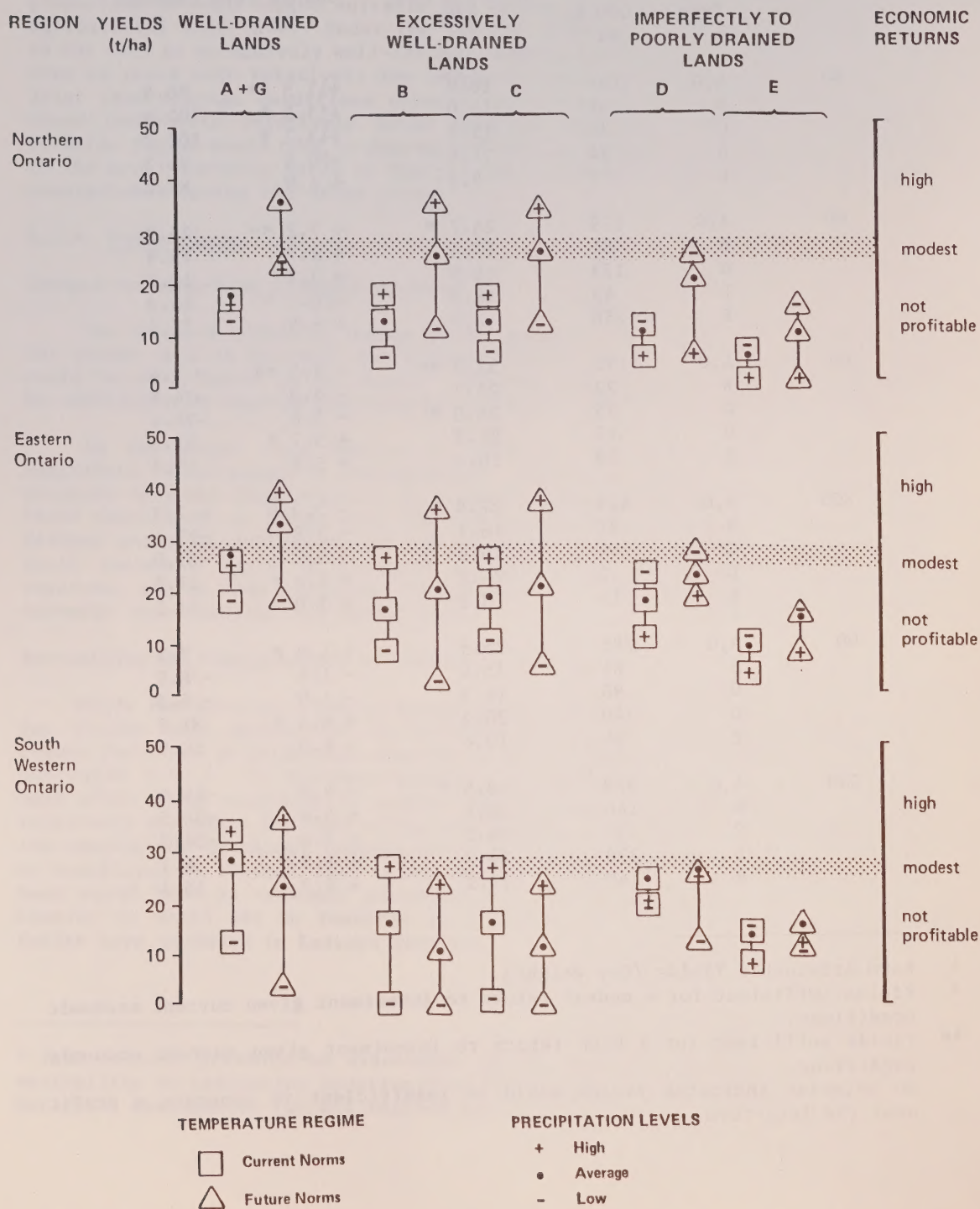


TABLE 5.8: EFFECTS OF CLIMATIC CHANGE AND ALTERNATIVE PRECIPITATION LEVELS ON THE ECONOMIC SUITABILITY OF LAND FOR FODDER CORN

REGION	LAND AVAILABILITY (000's ha)	CLIMATIC REGIME	ECONOMIC SUITABILITY GIVEN ALTERNATIVE PRECIPITATION LEVELS		
			Low	Average % of Region	High
Northern Ontario	343	Current	0	0	0
		Future	0	61	31
Eastern Ontario	920	Current	0	20	47
		Future	0	24	67
South Western Ontario	1761	Current	0	53	71
		Future	0	19	53
Ontario	5183	Current	0	34	63
		Future	0	43	64

The largest increases in risks to production stemming from climatic change and variability would probably occur in South Western Ontario. The specified changes in long-term climatic norms would contribute to about a three-fold reduction in the area of land that would be economically suitable for fodder corn production. While these losses could be recouped to some extent during those years in which precipitation exceeds average levels, these benefits would be eroded during the driest years.

5.1.5 Hay¹

Changes in Long-Term Climatic Norms

The impacts of a CO₂ induced climatic change on the regional opportunities for hay production would be considerably smaller than the effects on other field crops. In Eastern, South Central and South Western Ontario, the longer growing season would permit an extra cut, resulting in considerable increases in production opportunities for hay (Table 5.9). Elsewhere in Ontario, the number of cutting periods would not change under the altered climate and the production prospects for hay would not differ appreciably from the present.

¹ Information on hay yields required to attain a return to investment are not available and hence these analyses pertain to the biophysical opportunities for production.

TABLE 5.9: EFFECTS OF CHANGES IN LONG-TERM CLIMATIC NORMALS ON HAY YIELDS

Region	Land Type	Area 000's	Current FAY ¹ t/ha	Change from Current %	
NO	A,G	134	9.9	0.0	- 0.3
	B	41	6.7	0.0	0.3
	C	36	6.8	0.0	0.4
	D	24	8.8	+0.2	2.5
	E	77	5.9	+0.2	3.9
EO	A,G	179	9.9	+0.8	7.6
	B	81	6.8	+0.6	9.1
	C	173	7.3	+0.7	9.0
	D	45	9.2	+1.0	10.8
	E	256	6.2	+0.7	11.5
CO	A,G	170	9.1	-0.5	- 5.2
	B	22	5.9	-0.4	- 6.3
	C	55	6.4	-0.4	- 5.8
	D	12	8.4	-0.4	- 5.2
	E	19	5.8	-0.3	- 5.6
SCO	A,G	429	10.8	+1.3	11.7
	B	37	7.4	+1.0	13.0
	C	44	7.6	+1.0	13.1
	D	2	9.3	+1.1	12.2
	E	16	6.3	+0.8	11.9
WO	A,G	785	9.8	-0.3	- 2.6
	B	64	6.3	-0.3	- 4.1
	C	98	6.6	-0.3	- 3.8
	D	40	8.9	-0.4	- 4.8
	E	96	6.1	-0.3	- 5.3
SWO	A,G	929	11.2	-1.7	-14.9
	B	166	7.6	+1.9	24.2
	C	155	7.7	+1.8	23.9
	D	338	9.5	0.0	- 0.4
	E	140	6.5	+3.0	46.8

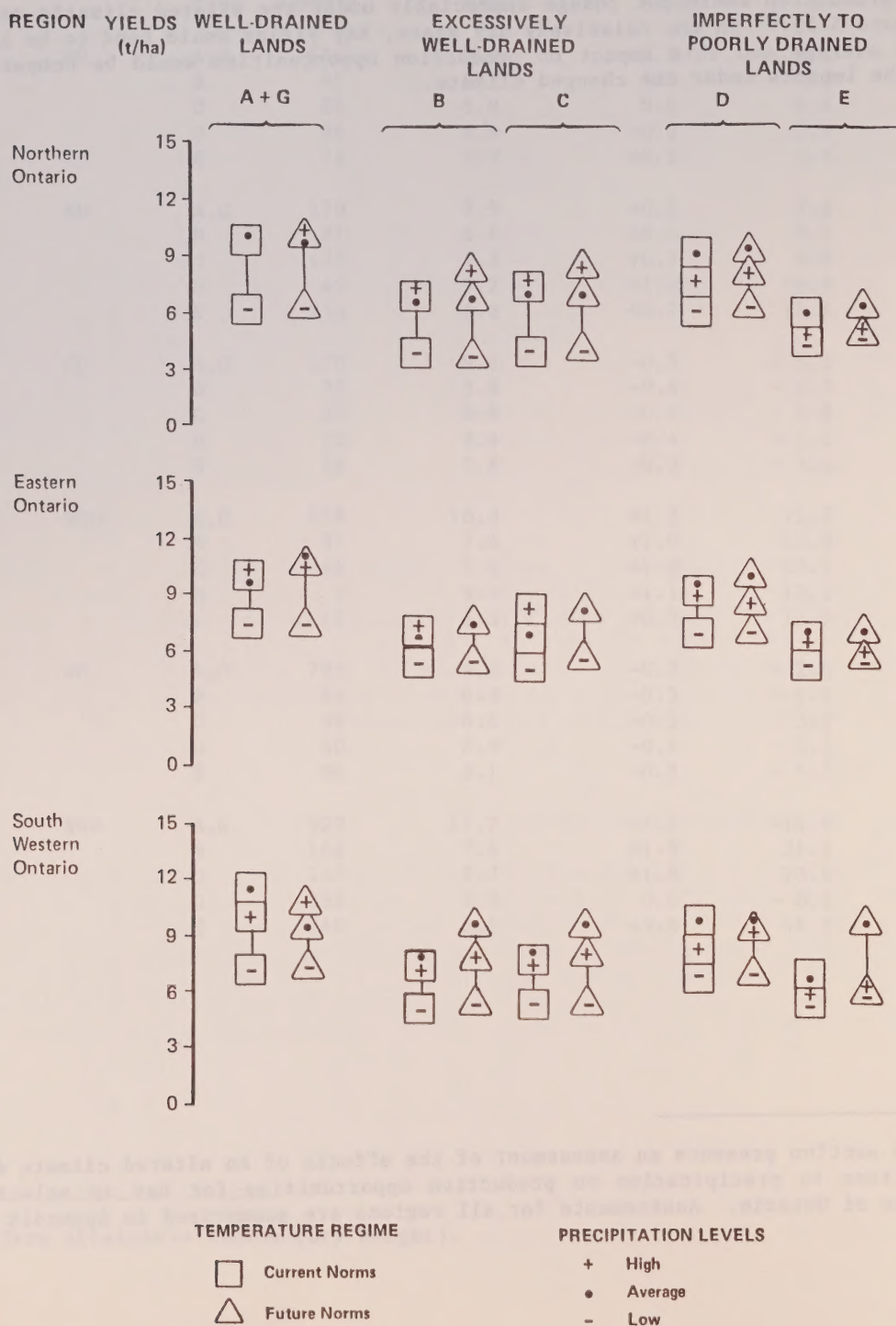
¹ Farm Attainable Yields (Dry Weight).

Variability in Precipitation and Risks to Production

The degree to which variation in year to year precipitation poses a risk to hay production would not change appreciably under the altered climatic regime (Figure 5.5).¹ In the relatively dry years, hay yields would tend to be lower than average and this impact on production opportunities would be comparable to the impacts under the changed climate.

¹ This section presents an assessment of the effects of an altered climate and variations in precipitation on production opportunities for hay in selected regions of Ontario. Assessments for all regions are summarized in Appendix 6.

FIGURE 5.5: REGIONAL EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON YIELDS FOR HAY



5.2 Effects on Production Opportunities for Horticultural Crops

5.2.1 Sweet Corn

The principal climatic requirements for the production of sweet corn are relatively long growing periods, preferably in excess of 133 days, and sufficient heat (i.e. more than 2000 corn heat units for most cultivars) for the crop to reach maturity. The longer growing season and warmer summer temperatures stemming from an enriched CO₂ environment would enhance the production opportunities for sweet corn considerably throughout the province (Table 5.10).

The greatest increases in production opportunities under the altered climatic regime would occur in Northern Ontario where climate currently imposes severe constraints on sweet corn production. All of the other regions would have a very good climatic potential for the crop under the changed climate.

TABLE 5.10: EFFECTS OF CLIMATIC CHANGE ON THE PRODUCTION OPPORTUNITIES FOR SWEET CORN

REGION	CLIMATIC REGIME	CLIMATIC POTENTIAL FOR SWEET CORN			
		Poor	Fair	Good	Very Good
		% of Region			
Northern Ontario	Current	94	2	4	0
	Future	0	0	28	73
Eastern Ontario	Current	13	13	75	0
	Future	0	0	0	100
Central Ontario	Current	3	0	97	0
	Future	0	0	0	100
South Central Ontario	Current	0	0	74	27
	Future	0	0	0	100
Western Ontario	Current	0	0	66	34
	Future	0	0	0	100
South Western Ontario	Current	0	0	9	91
	Future	0	0	0	100

5.2.2 Grapes

Grapes are representative of horticultural crops which are very sensitive to winter temperatures. Winter extremes ranging from -26°C to -29°C are tolerable but not preferable, and lower temperatures will prohibit the crop's production. More than 2800 CHU's are required for the crop to mature. The anticipated increases in summer and winter temperatures would not be sufficient to enhance the prospects for grape production in Northern, Eastern and Central Ontario (Table 5.11). In South Central and Western Ontario, it is estimated that more than one-third of the land in each of these regions will have a good potential for grape production. The largest increases in the production opportunities for the crop are likely to occur in South Western Ontario where about one-fifth of the region would be especially well-suited for grapes.

TABLE 5.11: EFFECTS OF CLIMATIC CHANGE ON THE PRODUCTION OPPORTUNITIES FOR GRAPES

REGION	CLIMATIC REGIME	CLIMATIC POTENTIAL FOR GRAPES				
		None	Poor	Fair % of Region	Good	Very Good
Northern Ontario	Current	100	0	0	0	0
	Future	28	73	0	0	0
Eastern Ontario	Current	100	0	0	0	0
	Future	0	100	0	0	0
Central Ontario	Current	100	0	0	0	0
	Future	0	100	0	0	0
South Central Ontario	Current	74	27	0	0	0
	Future	0	62	0	38	0
Western Ontario	Current	66	34	0	0	0
	Future	0	62	0	37	0
South Western Ontario	Current ¹	9	91	0	0	0
	Future	0	8	0	71	21

¹ These analyses are conducted at a scale of 1:5 million and hence relatively small areas in the region that are presently used for grape production are not detected.

5.2.3 Apples

Of the horticultural crops which are sensitive to extreme winter temperatures, apples represent the hardier crops within the category. Apples require more than 1900 CHU's for commercial production to be viable, and the trees are damaged if extreme winter temperatures drop below -35°C . The longer, warmer summers and milder winters associated with a $2 \times \text{CO}_2$ atmosphere would expand the production prospects for apples to all regions in Ontario (Table 5.12). Constraints imposed by severe winter temperatures in Eastern and Northern Ontario would be removed under the altered climate. Considerable increases in production opportunities could be expected in Central, South Central and Western Ontario.

TABLE 5.12: EFFECTS OF CLIMATIC CHANGE ON THE PRODUCTION OPPORTUNITIES FOR APPLES

REGION	CLIMATIC REGIME	CLIMATIC POTENTIAL FOR APPLES				
		None	Poor	Fair % of Region	Good	Very Good
Northern Ontario	Current	4	93	3	0	0
	Future	0	0	1	97	2
Eastern Ontario	Current	0	13	70	18	0
	Future	0	0	0	72	28
Central Ontario	Current	0	3	9	89	0
	Future	0	0	0	18	82
South Central Ontario	Current	0	0	3	59	38
	Future	0	0	0	1	99
Western Ontario	Current	0	0	28	21	51
	Future	0	0	0	0	100
South Western Ontario	Current	0	0	0	0	100
	Future	0	0	0	0	100

5.3 Production Opportunities for New Crops Under the Altered Climatic Regime

Elevated levels of CO₂ would lead to considerable increases in temperatures, and it is anticipated that the climate in South Western Ontario under this altered regime would resemble the current climate in southern Illinois, southern Indiana, southern Ohio and Maryland (Appendix 11).

Many of the crops currently grown in these states are presently grown in Ontario. Corn, soybeans, wheat, hay and oats are the most important crops in Illinois, Indiana and Ohio. In the southern parts of Illinois and Indiana, peaches, apples, tomatoes, strawberries and melons are grown. Tobacco can also be found in the southeastern region of Indiana. The frost-free season ranges from 190 days in southern Illinois to 225 days in some parts of Maryland. This compares well with the longer growing seasons that would be expected in Western, South Central and South Western Ontario under the altered climatic regime. The estimated growing season precipitation level for South Western Ontario under the altered climate is lower than current levels in the central and coastal United States. This reduction could adversely affect potential crop yields in Ontario under the altered climatic regime.

Peanut production in the United States is concentrated in Texas, Oklahoma, Alabama, Florida, Georgia, South and North Carolina, and Virginia where a long frost-free season and warm temperatures exist for optimum peanut growth. While the climatic conditions in southern Ontario under the altered climatic regime would be more favourable for peanuts, commercial production opportunities would be limited to sandy soils.

It would appear that the opportunities for introducing new crops to Ontario under the altered climatic regime would be quite limited. Potential benefits of these climatic changes would probably be noticeable in two areas. First, the longer season and higher yielding cultivars that are currently used in the Central United States would in all likelihood be suitable to Ontario. Second, the warmer temperatures, especially during the winter months, will be much more favourable for fruits and vegetables, and production would not be limited to lakeside locations. It should be feasible to produce a wide range of horticultural crops over large portions of the province under the altered climatic regime.

5.4 Concluding Comment

This section assesses the effects on regional opportunities for crop production of climatic change. Consistent with previous sections, the analyses isolate the impacts of altered climatic regimes while holding all other conditions constant. While this approach facilitates interregional comparisons of the opportunities for crop production, it is not intended to measure the impacts of climatic change on Ontario's food production. These sorts of analyses require procedures that can simultaneously consider yield response to climatic changes for several crops relative to other conditions relating to resource availability and production levels.

6 EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON ONTARIO'S FOOD PRODUCTION POTENTIAL

This section examines the effects of the altered climatic regime and variability in precipitation on Ontario's potential for food production. The analyses consider yield response to climatic change for several crops simultaneously in all regions of Ontario relative to other factors such as land available for crop production, crop production levels and land use practices which would maintain soil quality, and thereby measure the aggregate implications of climatic change on the provincial prospects for food production. In other words, the findings indicate the extent to which losses in productivity in one region might be offset by higher yields elsewhere. The section commences with an appraisal of the effects of changes in long-term climatic normals on the province's potential for total crop production. It concludes with an investigation of impacts of alternative levels of precipitation on provincial crop production potential under the current and altered climatic regimes.

6.1 Production Potential Given Changes in Long-Term Climatic Normals

The effects of changes in long-term climatic norms on Ontario's potential for food production are summarized in Table 6.1. Scenario 1 is the base scenario and representative of present environmental and socio-economic conditions in Ontario. Under these conditions it is estimated that Ontario's potential for food production surpasses current levels of production by about 66 per cent. Production increases in particular crops beyond these levels would be feasible, but this would diminish the production potential for at least one other crop.

Scenario 2 differs from Scenario 1 in that it is assumed that a doubling of atmospheric concentrations of CO₂ has resulted in a considerable change in climatic normals with concomitant changes in crop yields. The estimated adjustments to long-term climatic normals implies considerable increases in crop stress stemming from moisture deficits and lower yields would be expected on lands with low tolerance to droughty conditions. Other conditions relating to land availability, provincial levels of production, etc. are identical under the two scenarios. The changes in long-term climatic normals imply a decline in Ontario's potential for food production, but the overall prospects for crop production would continue to exceed current levels of production (Table 6.1). Under Scenario 2, it is estimated that the productive capacity of Ontario's land resources would be approximately 60 per cent greater than present levels of provincial production, compared with +66 per cent under the base scenario.

6.2 Production Potential Given Variability in Precipitation

The effects of alternative levels of precipitation on Ontario's potential for food production are presented in Figure 6.1. The analyses are conducted relative to present normals for temperature and relative to possible changes in the thermal regime.

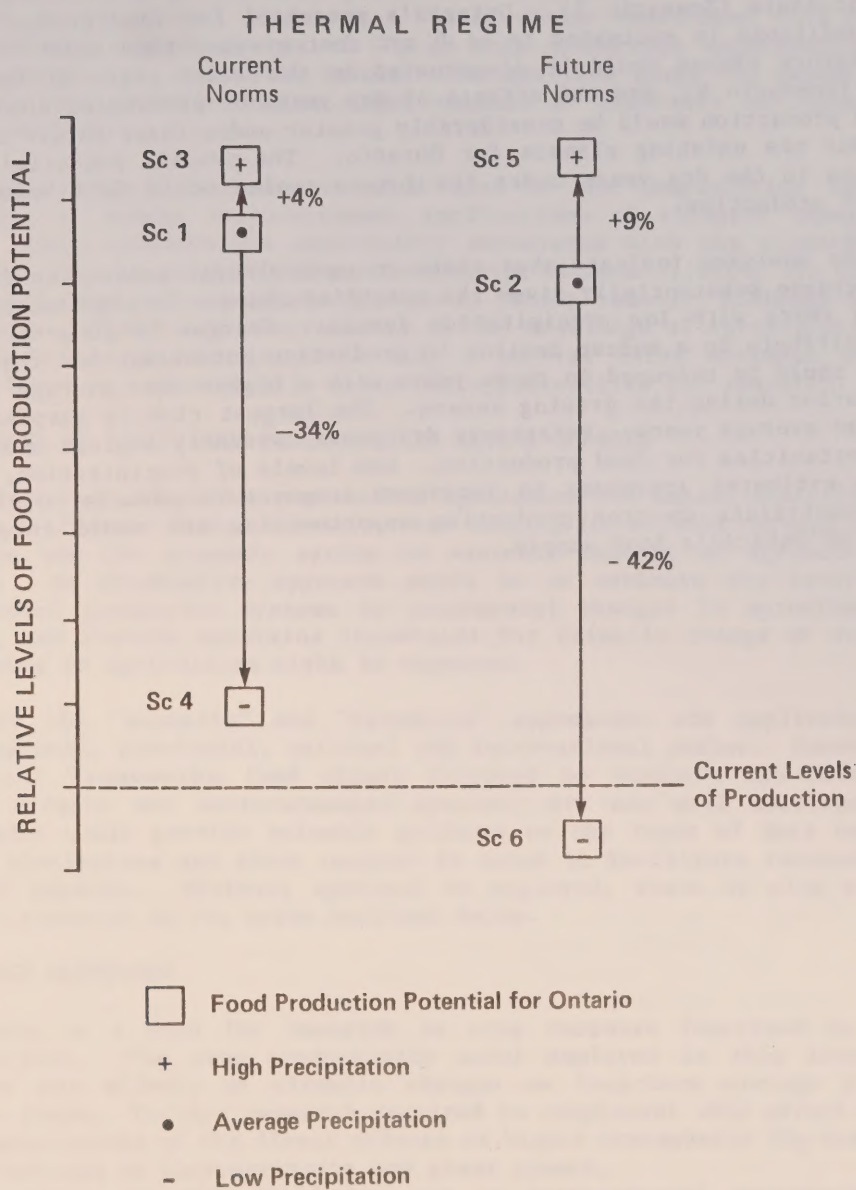
TABLE 6.1: ONTARIO'S POTENTIAL FOR FOOD PRODUCTION GIVEN CHANGES IN LONG-TERM CLIMATIC NORMALS

CROP	CURRENT PRODUCTION 000's T	PRODUCTION POTENTIAL GIVEN:	
		CURRENT NORMS (SCEN 1) 000's T	FUTURE NORMS (SCEN 2) 000's T
Grain Corn	4693	7804	7485
Barley	1059	1761	1689
Oats	664	1104	1059
Winter Wheat	639	1063	1019
Soybeans	707	1176	1127
Hay	5165	8590	8238
Fodder Corn	7022	11678	11200
Potatoes	369	614	589
Improved Pasture	4729	7865	7543
Unimproved Pasture	331	550	528
PRODUCTION POTENTIAL RELATIVE TO CURRENT PRODUCTION (% change)		+66	+60

Deficits or surpluses in the seasonal supply of water available for crop growth presently occur throughout much of Ontario and impose constraints on the opportunities for food production. Relative to current normals for temperature and precipitation (Scenario 1), it is estimated that Ontario's crop production potential exceeds current levels of production by 66 per cent. This potential is however sensitive to existing fluctuations in seasonal levels for precipitation. Precipitation levels above the current norm tend to relieve moisture deficits somewhat (Scenario 3) and thereby contribute to a modest increase in food production prospects throughout Ontario. Crop moisture stresses are aggravated considerably in years with low levels of precipitation during the growing season. Relative to existing climatic normals, Ontario's potential for food production would be reduced by about one-third (Scenario 4). The productive capacity of Ontario's agricultural land resources under these conditions would only just exceed current averages for crop production.

The risks to the provincial potential for agricultural production that are imposed by variability in precipitation would be expected to increase under the altered climatic regime. The estimated changes in long-term normals for temperature and precipitation imply a less favourable climate for many of the crops presently grown in Ontario. The provincial potential for food

FIGURE 6.1: EFFECTS OF CLIMATIC CHANGE AND VARIABILITY ON FOOD PRODUCTION POTENTIAL IN ONTARIO



production would be reduced under this new climate, but still exceed present levels of food production (Figure 6.1, Scenarios 2 and 1). Precipitation levels above the estimated change in the long-term normals would reduce crop stress under the altered regime and thereby create a more favourable climate for agriculture (Scenario 5). Ontario's potential for food production under these conditions is estimated to be 9 per cent greater than under Scenario 2. Crop moisture stress would be accentuated in the drier years of the altered climate (Scenario 6), and the effects of dry years on provincial opportunities for food production would be considerably greater under these future conditions than under the existing climate for Ontario. The overall potential for crop production in the dry years under the future regime would fall below current levels of production.

These analyses indicate that risks to agricultural production in Ontario would increase substantially given the specified changes in climate, especially in those years with low precipitation levels. Changes in long-term normals would contribute to a modest decline in production potential, but these opportunities could be recouped in those years with a higher than average level for precipitation during the growing season. The largest risk is associated with drier than average years. Relatively dry years currently impinge upon provincial opportunities for food production. Low levels of precipitation, combined with the estimated increases in long-term temperature normals, would impose severe constraints on crop production opportunities and could threaten the security of Ontario's food supply.

7 DIRECTIONS FOR FUTURE RESEARCH

This report examines the implications of an altered climatic regime on the prospects for agricultural production in Ontario. More specifically, it assesses the impacts of long-term climatic change associated with a doubling in atmospheric concentrations of CO₂ on crop production opportunities at the farm, regional and provincial levels. The analyses gauge the extent to which change in the climatic regime might enhance or constrain the prospects for food production.

This research has demonstrated some of the complexities involved in attempting to assess socio-economic implications of climatic changes. Not only is there considerable uncertainty associated with the climatic changes themselves, but knowledge of the relationships between climate, the biophysical environment, and socio-economic systems is scanty indeed. Although this study represents a significant contribution to the knowledge of agricultural impacts of climatic change, it is still only a partial first estimate of limited scope. There are considerable needs and opportunities for research.

DEVELOPMENT OF ANALYTICAL PROCEDURES TO ASSESS IMPACTS

This report adopted a conventional procedure for impact analysis; namely, assuming a climatic change scenario, then tracing its effects through biological processes and the economic system to estimate impacts on agricultural production. An alternative approach would be to estimate the sensitivity of agricultural production systems to incremental changes in agroclimatic conditions, and thereby determine thresholds for climatic change at which major adjustments in agriculture might be expected.

Both the "scenario" and "threshold" approaches are applicable at the farm, regional, provincial, national and international scales. However, these analytical frameworks (and others designed to evaluate the relationships between climate and socio-economic systems) are not well developed. Such development would provide valuable guidance on the types of data needed from climate simulations and other sources in order to facilitate reasonable estimates of impacts. Whatever approach is employed, there is also a pressing need for research in the areas outlined below.

CROP YIELD RESPONSES

There is a need for research on crop response functions to climatic perturbations. The crop productivity model employed in this investigation assesses the effects of climatic changes on long-term average yields for specific crops. Further research required to complement this effort include:

- assessments of the direct effects of higher atmospheric CO₂ concentrations on photosynthesis and plant growth,
- analyses of crop yield response to intraseasonal variations in climatic conditions, and
- the development of productivity models for horticultural crops and for other crops which might be introduced.

This research would expand the types of analyses which could be conducted at each geographic scale, and also provide direction for future developments in

crop breeding.

FARM AND REGIONAL ASSESSMENTS

There is a need for research on farm responses to changes in yields relative to changes in other conditions. This study has demonstrated that it is feasible to appraise the economic implications of altered climates for specific farm enterprise types. The analyses should be expanded to consider a wider range of farm enterprises and alternative economic conditions. This would indicate those types of farming which would be most sensitive to climatic change and those enterprises which would be better able to adapt. Alternatively, research on farm level responses to current variability in climate could contribute to this area. It is also necessary to develop means of aggregating such information to be able to estimate sensitivities and response functions of regional agricultural systems to climatic perturbations.

INTERSECTOR ASSESSMENTS

The strategy employed in this project isolates the impacts of climatic change on agriculture from changes occurring in other sectors. The potential impacts of climatic change are far reaching and would potentially affect all sectors in society. Furthermore, the structure of society can be expected to evolve considerably during the time frame associated with a doubling in CO₂. For these reasons, it is crucial that research on climatic impact be expanded to consider the major links between sectors and the competition for resources amongst these sectors. From the agricultural perspective, examples include:

- implications of shifts in agriculture for infrastructure and trade,
- demands for water for irrigation versus urban and industrial use, and transportation, and
- demands for land for crop production, recreation, forestry, housing and so on.

INTERPROVINCIAL AND INTERNATIONAL ASSESSMENTS

Within the realm of climatic change research, the factor which might have the greatest influence on the future of Ontario agriculture is the effects of climatic change on agriculture in Ontario relative to its impacts elsewhere. For example, if climatic change results in a much larger reduction in the opportunities for crop production in other parts of North America than in Ontario, Ontario's comparative advantage for food production could be enhanced. It is critical not only to investigate agricultural sensitivities and responses in other parts of Canada but also to investigate the implications of changes in agricultural production opportunities in other parts of the world. A first step leading towards this type of integrative analysis could include a qualitative assessment of the relative impacts of climatic change on agricultural production opportunities throughout Canada and the United States. This assessment could provide a foundation for estimating shifts in comparative advantage, possible adjustments to market demands, and some implications for interprovincial and international trade in agricultural commodities. Such analyses would provide a more comprehensive basis for judging the likely impacts of climatic change on Ontario agriculture.

RESPONSE OPTIONS AND POLICY IMPLICATIONS

An important rationale for studies into socio-economic impacts of climatic changes is to identify possible responses to the opportunities and constraints created by the changes. Some possible responses are implicit in this study, for example, increased demand for irrigation in moisture-deficit areas, increased demand for drought-resistant hybrids, increased land development and demand for infrastructure in northern Ontario, or need for production expertise and marketing arrangements for new crops. These topics will require research once some consensus is reached on likely impacts on the agricultural sector.

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APPENDIX 1: EFFECTS OF A DOUBLING IN CO₂ ON MONTHLY CLIMATIC NORMALS

Location of Data Points

Point	Lat.	Long.	Point	Lat.	Long.
B1	42.0	80.0	B7	50.0	90.0
B2	46.0	80.0	B8	50.0	85.0
B3	46.0	75.0	B9	50.0	80.0
B4	46.0	85.0	B10	54.0	90.0
B5	46.0	90.0	B11	54.0	85.0
B6	50.0	95.0	B12	42.0	75.0

Change in Mean Monthly Temperature (°C from current normals)

Pnt ¹	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B1	5.8	5.5	5.1	4.4	3.6	3.2	3.3	4.2	4.7	5.0	5.5	5.8
B2	5.8	5.5	5.1	4.4	3.7	3.2	3.4	4.0	5.0	5.2	5.4	5.8
B3	5.8	5.2	4.8	4.4	3.9	3.6	3.7	4.0	4.2	4.4	5.0	5.7
B4	5.8	5.6	5.1	4.4	3.6	3.1	3.2	4.0	4.8	5.1	5.4	5.8
B5	5.8	5.7	5.3	4.6	3.8	3.4	3.5	4.1	4.7	5.0	5.4	5.7
B6	5.6	5.6	5.4	4.5	3.8	3.1	2.9	3.1	3.8	4.7	5.3	5.5
B7	5.6	5.6	5.3	4.1	3.6	3.0	2.9	3.1	3.7	4.6	5.2	5.5
B8	5.6	5.6	5.1	4.1	3.2	2.8	2.9	3.2	3.7	4.4	5.1	5.4
B9	5.7	5.6	5.1	4.1	3.2	2.9	2.9	3.0	3.5	4.3	5.1	5.6
B10	6.5	6.2	5.5	4.1	3.6	3.1	3.0	3.3	3.9	4.8	5.7	6.3
B11	6.9	6.5	5.4	4.1	3.1	2.8	3.0	3.4	3.9	4.7	5.7	6.6
B12	5.6	5.1	4.8	4.5	4.0	3.8	4.0	4.3	4.4	4.5	5.0	5.6

¹ Data point.

APPENDIX 1 Continued

Change in Total Monthly Precipitation (as a % of current normals)

Pnt	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B1	112.5	112.0	111.5	111.1	107.1	107.4	108.0	95.5	84.2	88.9	100.0	108.7
B2	108.7	113.0	112.5	112.0	107.4	111.5	108.3	100.0	88.9	94.4	105.0	109.1
B3	104.3	104.3	104.2	103.8	103.4	106.9	112.0	105.0	83.3	73.7	81.8	91.7
B4	113.0	112.5	112.0	107.7	111.5	107.7	108.3	100.0	94.4	100.0	105.0	113.6
B5	114.3	112.5	114.3	112.5	108.6	105.7	103.1	100.0	100.0	100.0	105.0	115.0
B6	117.6	122.2	113.0	106.5	105.6	108.3	112.5	107.1	100.0	109.5	122.2	116.7
B7	117.6	116.7	109.5	107.7	103.2	110.0	111.1	113.0	110.0	116.7	123.5	123.5
B8	111.8	105.9	105.9	105.3	100.0	109.1	115.8	126.7	141.7	138.5	125.0	117.6
B9	111.8	111.8	111.8	110.5	109.1	113.0	120.0	125.0	130.8	121.4	125.0	117.6
B10	112.5	118.7	115.8	108.3	107.1	114.3	115.4	113.0	115.0	116.7	117.6	118.7
B11	120.0	113.3	106.2	105.6	105.0	110.0	116.7	126.7	138.5	128.6	125.0	118.7
B12	104.2	104.2	100.0	100.0	100.0	103.3	103.8	95.2	77.8	70.0	78.3	88.0

Source: Atmospheric Environment Service, Environment Canada

APPENDIX 2: EFFECTS OF THE ALTERED CLIMATIC REGIME ON SELECTED AGROCLIMATIC PARAMETERS

Current Climatic Conditions

REGION	GSS	GSE	GSL DAYS	CHU	DD	TEMP °C	PE mm	LOW	PREC mm AVE	HIGH
NO	27 MAY	19 SEPT	115	2047	1202	15.2	357	218	325	432
CO	11 MAY	4 OCT	146	2905	1738	16.7	468	277	360	454
WO	13 MAY	14 OCT	154	2988	1775	16.4	469	277	390	476
EO	14 MAY	29 SEPT	138	2690	1596	16.4	421	296	385	481
SCO	10 MAY	9 OCT	152	3022	1799	16.7	486	268	378	457
SWO	6 MAY	19 OCT	166	3318	1970	16.8	519	284	406	491

Future Climatic Conditions

REGION	GSS	GSE	GSL DAYS	CHU	DD	TEMP °C	PE mm	LOW	PREC mm AVE	HIGH
NO	9 MAY	19 OCT	163	3305	2001	17.1	587	340	460	635
CO	18 APR	10 NOV	206	4420	2759	18.3	737	393	510	576
WO	18 APR	15 NOV	211	4515	2789	18.1	739	354	529	640
EO	23 APR	27 OCT	187	4054	2506	18.3	665	371	489	606
SCO	16 APR	15 NOV	213	4567	2829	18.2	757	354	528	639
SWO	11 APR	20 NOV	223	4877	3009	18.4	798	374	550	666

GSS: Growing Season Start
 GSE: Growing Season End
 GSL: Growing Season Length
 CHU: Corn Heat Units for GSL
 TEMP: Mean Daytime Temperature for GSL
 DD: Degree Days for GSL
 PE: Potential Evapotranspiration for GSL
 PREC: Precipitation for GSL

Regions: NO Northern Ontario EO Eastern Ontario
 CO Central Ontario SCO South Central Ontario
 WO Western Ontario SWO South Western Ontario

APPENDIX 3: APPLICATION OF THE CASH GRAIN FARM MODEL TO ESTIMATE THE EFFECTS OF CLIMATIC CHANGE ON MAXIMUM NET RETURNS

Pfeiffer's (1976)¹ Ontario automatic cropping budget system for cash grain farms utilizes linear programming techniques to estimate maximum net returns for a farm enterprise. Operation of the system requires:

- data on the availability of resources including land, labour and farm machinery,
- production functions for grain corn, soybeans and wheat (i.e. yields given specified levels of inputs such as land, fertilizer, seed costs, etc.), and
- marketing data including storage and transportation costs, drying costs, and selling prices.

Default values are provided for all model parameters, and these are based upon a "typical" cash grain farm in South Western Ontario during 1977-1978. The system can also calculate maximum net returns given changes in one or more parameters.

In this study, the cash grain farm model is employed to estimate the effects of climatic change on maximum net returns at the farm level and on the optimal allocation of resources available to the farm. Default values are used for each model parameter except crop yields. Selected default values employed in this study are listed below and described in greater detail in Pfeiffer (1976).

A crop yield model developed and implemented by the LEG (1983)² is employed to estimate the cumulative impacts of climatic change and of alternative planting-harvesting dates on farm obtainable yields for grain corn, soybeans and winter wheat. Data inputs to the crop productivity model are presented in this appendix. The criteria and assumptions used to compile these data follow.

¹ Pfeiffer, W.C. 1976. The Ontario automatic cropping budget system for cash grain farms: A tool for detailed farm management. ISSN 0318-1812 AEED/76/3. School of Agricultural Economics and Extension Education, University of Guelph. Guelph.

² Land Evaluation Group. 1983. Analysis of the production possibilities of Ontario agriculture: Regional assessments of the prospects for sustainable agricultural production, Volume I. Publication No. LEG-16. University School of Rural Planning and Development, University of Guelph. Guelph.

SELECTED DEFAULT VALUES USED IN THE CASH GRAIN FARM MODEL

MODEL PARAMETER		DEFAULT VALUE ¹	
AVAILABLE RESOURCES	Land: Owned	400 acres	
	Rental	100 acres	
	Labour: On-farm permanent	1 man	
	Hired, part-time	\$4.00/hour	
	Tractors (70 hp)	2	
	On-farm drying capacity	200 bu/day	
	On-farm storage capacity for shelled corn and soybeans	62,000 bu	
PRODUCTION COSTS	Fixed land charges	\$60/acre	
	Land rental	\$60/acre	
	Tractor operations	\$3.27/hour	
	Corn production:	Fertilizer	\$29.00/acre
		Tractor operations:	
		- preharvest	1.54 hr/acre
		- harvest	3.87 hr/acre
		On-farm drying	\$.15 bu/15% pts
		Drying at elevator	\$.25 bu/15% pts
	Soybean production:	Fertilizer	\$12.50/acre
		Tractor operations:	
		- preharvest	1.34 hr/acre
		- harvest	3.10 hr/acre
	Wheat production:	Fertilizer	\$23.00/acre
	Tractor operations:	2.09 hr/acre	

¹ Imperial units of measurement are employed in the Ontario automatic cropping budget system for cash grain farmers. For this report, model output has been converted into metric units.

SELECTED DEFAULT VALUES Continued

	MODEL PARAMETER	DEFAULT VALUE
MARKETING DATA	Corn: Farm dried to 15.5% moisture and	
	- sold at harvest	\$2.30/bu
	- stored and sold	\$2.50/bu
	High moisture corn sold at harvest	\$2.10/bu
	Soybeans: Sold at harvest	\$5.25/bu
	Stored and sold	\$5.75/bu
	Wheat	\$3.25/bu

ASSUMPTIONS AND DATA EMPLOYED TO ESTIMATE THE EFFECTS OF CLIMATIC CHANGE AND ALTERNATIVE PLANTING-HARVESTING DATES ON CROP YIELDS

Geographic Location: The "typical" farm is a cash grain farm in South Western Ontario. Map unit C1002 on the Soils of Canada Map accounts for a greater portion of the region than any other map unit. For the purpose of this study, it is assumed that the "typical" farm is located within map unit C1002.

Planting Periods: The overall planting period for grain corn and soybeans is divided into several seven day planting periods. The first planting period is established as the one-week period surrounding the growing season start (GSS). May 5th is the estimated GSS under current climatic conditions, and four planting periods are defined. This is consistent with present farming practices in that grain corn and soybeans are planted during May. Under Scenario B, the estimated GSS is April 10, and six planting periods are defined. The extended growing season under Scenario B would allow for overall increases in the planting period. Planting periods for winter wheat coincide with the first two harvesting periods for soybeans (see below).

Harvest Periods: The harvest periods for grain corn and for soybeans are partitioned into three periods. For grain corn, the following criteria are used to establish harvest periods. The entire harvest period comprises three consecutive 21-day harvest periods and the first period is defined as the 21 days prior to the growing season end (GSE). For soybeans, the second and third harvest periods coincide with the first and second harvest periods for grain corn respectively, and the first harvest period for soybeans is defined as the 14-day period which immediately precedes the second harvest period for the crop. October 19 and November 22 are the estimated GSE under current climatic conditions and Scenario B respectively.

The default values for the winter wheat harvest period are employed in this study. It is a contiguous five week period commencing on June 14 and ending on July 20.

Crop Growing Period: For the purposes of this investigation, the growing period for grain corn and for soybeans is effectively constrained by the following three factors: climate, biological capacity of the crop, and farm management practices. Climate is represented by the GSS, GSE and growing season length (GSL). The current GSS and GSE for map unit C1002 are May 5 and October 20, with a GSL of 169 days. Under Scenario B, the GSS and GSE are estimated to be April 10 and November 22, with a GSL of 227 days. Biological capacity of a particular crop is incorporated as the number of days that a crop can effectively convert energy into usable biomass (180 days for grain corn, and 130 days for soybeans). Farm management is represented by the number of days between the planting and harvesting dates. The planting date is estimated as the mid-point of a particular planting period and the harvest date is defined as the first day in a specific harvest period.

The estimated growing period for grain corn and for soybeans is determined by the factor which is most constraining (i.e. fewest days). It is assumed that the growing period is an uninterrupted period and that it commences on the planting date.

Constraint-Free Yields: Constraint-free crop yields (CFY) represent the capacity of a particular crop to transform available energy into usable biomass. CFY's for grain corn, soybeans and winter wheat under current climatic conditions and Scenario B have been estimated by Agriculture Canada for the LEG (1985).¹

The estimated CFY for grain corn under current climatic conditions for map unit C1002 is 11597 kg/ha over a 169 day crop growing period. For a 130 day period, ceteris paribus, the CFY for grain corn is estimated at 7302 kg/ha (Dumanski and Stewart, 1981)². Under the present climate, it is estimated that an average 110 kg/ha/day are added to the CFY between the 130th day and the 169th day of the growing period. For those combinations of planting and harvesting dates that result in a growing period of less than 169 days under current climatic conditions, the CFY for grain corn is estimated by reducing the CFY for a 169 day growing period by 110 kg/ha/day.

Under Scenario B, a CFY for grain corn has been estimated for map unit C1002 for a 180 day growing period. CFY for alternative growing periods under Scenario B are unavailable. In the absence of these data, a reduction factor of 110 kg/ha/day is used to estimate CFY for combinations of planting.

¹ Land Evaluation Group. 1985. Socio-economic assessment of the implications of climatic change for food production in Ontario. Publication No. LEG-22. University School of Rural Planning and Development, University of Guelph. Guelph.

² Dumanski, J. and R.B. Stewart. 1981. Crop production potentials for land evaluation in Canada. Land Resource Research Institute, Agriculture Canada. Ottawa.

Edaphic Characteristics: It is assumed that the "typical" cash grain farm is located on well-drained loamy soils, with an available water holding capacity of 150 mm. It is also assumed that soil moisture is recharged fully during the winter months.

Moisture-Related Variables: Precipitation, potential evapotranspiration, soil-moisture deficit or surplus and a moisture stress factor are estimated for the crop growing period. Precipitation and potential evapotranspiration are estimated using data derived from current climatic normals and from future climatic normals. Procedures for estimating soil moisture deficit or surplus and a moisture stress factor are outlined in Appendix 4.

Crop Moisture Content: Moisture content at harvest for soybeans and winter wheat is set at 15 per cent. For grain corn, moisture content is reduced from 31 per cent for the first harvest period, to 23 per cent for the second harvest period, to 20 per cent for the third harvest period.

INPUT DATA AND YIELD ESTIMATES FOR GRAIN CORN (CURRENT CLIMATIC REGIME)

SCENARIO: C CROP: GRAIN CORN MAP UNIT: C1002 AWHC: 150 mm

		PLANTING PERIOD			
		MAY 2- MAY 8	MAY 9- MAY 15	MAY 16- MAY 22	MAY 23- MAY 29
HARVEST PERIOD 1 SEPT 29 - OCT 19	GP	148	141	134	127
	CFY	9287	8517	7747	6977
	PREC	358	341	324	306
	PE	497	475	452	428
	SMDS	11	16	22	28
	MSF	0.75	0.77	0.79	0.81
	AY	7023	6586	6162	5696
	FAY	5267	4940	4622	4272
	% MOIS	31	31	31	31
HARVEST PERIOD 2 OCT 20 - NOV 9	GP	169	162	155	148
	CFY	11597	10827	10057	9287
	PREC	403	386	369	352
	PE	530	508	485	461
	SMDS	23	28	34	41
	MSF	0.80	0.81	0.84	0.86
	AY	9259	8840	8433	8020
	FAY	6944	6630	6325	6015
	% MOIS	23	23	23	23
HARVEST PERIOD 3 NOV 10 - DEC 1	GP	169	162	155	148
	CFY	11597	10827	10057	9287
	PREC	403	386	369	352
	PE	530	508	485	461
	SMDS	23	28	34	41
	MSF	0.80	0.81	0.84	0.86
	AY	9259	8840	8433	8020
	FAY	6944	6630	6325	6015
	% MOIS	20	20	20	20

NOTE: GP = Growing Period (days)
 CFY = Constraint-Free Yield (kg/ha)
 PREC = Precipitation (mm)
 PE = Potential Evapotranspiration (mm)
 SMDS = Soil Moisture Deficit or Surplus (cm)
 MSF = Moisture Stress Factor
 AY = Attainable Yield (kg/ha)
 FAY = Farm Attainable Yield (kg/ha)
 % MOIS = Crop Moisture Content at Harvest (%)

INPUT DATA AND YIELD ESTIMATES FOR GRAIN CORN (ALTERED CLIMATIC REGIME)

SCENARIO: B CROP: GRAIN CORN MAP UNIT: C1002 AWHC: 150 mm

		PLANTING PERIOD					
		APR 7- APR 13	APR 14- APR 20	APR 21- APR 27	APR 28- MAY 4	MAY 5- MAY 11	MAY 12- MAY 18
HARVEST PERIOD 1 NOV 1 - NOV 21	GP	180	180	180	180	177	170
	CFY	12252	12252	12252	12252	11922	11152
	PREC	443	439	435	430	420	402
	PE	612	605	596	584	567	543
	SMDS	-19	-16	-11	-4	3	9
	MSF	0.65	0.66	0.68	0.70	0.73	0.75
	AY	7939	8086	8295	8602	8669	8344
	FAY	5954	6065	6221	6452	6502	6258
	% MOIS	31	31	31	31	31	31
HARVEST PERIOD 2 NOV 22 - DEC 12	GP	180	180	180	180	180	180
	CFY	12252	12252	12252	12252	12252	12252
	PREC	443	439	435	430	427	424
	PE	612	605	596	584	570	554
	SMDS	-19	-16	-11	-4	7	20
	MSF	0.65	0.66	0.68	0.70	0.74	0.79
	AY	7939	8086	8295	8602	9081	9659
	FAY	5954	6065	6221	6452	6811	7244
	% MOIS	23	23	23	23	23	23
HARVEST PERIOD 3 DEC 13 - JAN 2	GP	180	180	180	180	180	180
	CFY	12252	12252	12252	12252	12252	12252
	PREC	443	439	435	430	427	424
	PE	612	605	596	584	570	554
	SMDS	-19	-16	-11	-4	7	20
	MSF	0.65	0.66	0.68	0.70	0.74	0.79
	AY	7939	8086	8295	8602	9081	9659
	FAY	5954	6065	6221	6452	6811	7244
	% MOIS	20	20	20	20	20	20

NOTE: GP = Growing Period (days)
 CFY = Constraint-Free Yield (kg/ha)
 PREC = Precipitation (mm)
 PE = Potential Evapotranspiration (mm)
 SMDS = Soil Moisture Deficit or Surplus (cm)
 MSF = Moisture Stress Factor
 AY = Attainable Yield (kg/ha)
 FAY = Farm Attainable Yield (kg/ha)
 % MOIS = Crop Moisture Content at Harvest (%)

INPUT DATA AND YIELD ESTIMATES FOR SOYBEANS (CURRENT CLIMATIC REGIME)

SCENARIO: C CROP: SOYBEANS MAP UNIT: C1002 AWHC: 150 mm

		PLANTING PERIOD			
		MAY 2- MAY 8	MAY 9- MAY 15	MAY 16- MAY 22	MAY 23- MAY 29
HARVEST PERIOD 1 SEPT 15 - SEPT 28	GP	130	130	130	130
	CFY	3860	3860	3860	3860
	PREC	318	317	315	313
	PE	458	452	444	433
	SMDS	10	15	21	30
	MSF	0.86	0.88	0.90	0.93
	AY	2987	3046	3115	3226
	FAY	2240	2285	2336	2420
HARVEST PERIOD 2 SEPT 29 - OCT 19	GP	130	130	130	130
	CFY	3860	3860	3860	3860
	PREC	318	317	315	313
	PE	458	452	444	433
	SMDS	10	15	21	30
	MSF	0.86	0.88	0.90	0.93
	AY	2987	3046	3115	3226
	FAY	2240	2285	2336	2420
HARVEST PERIOD 3 OCT 20 - NOV 9	GP	130	130	130	130
	CFY	3860	3860	3860	3860
	PREC	318	317	315	313
	PE	458	452	444	433
	SMDS	10	15	21	30
	MSF	0.86	0.88	0.90	0.93
	AY	2987	3046	3115	3226
	FAY	2240	2285	2336	2420

NOTE: GP = Growing Period (days)
 CFY = Constraint-Free Yield (kg/ha)
 PREC = Precipitation (mm)
 PE = Potential Evapotranspiration (mm)
 SMDS = Soil Moisture Deficit or Surplus (cm)
 MSF = Moisture Stress Factor
 AY = Attainable Yield (kg/ha)
 FAY = Farm Attainable Yield (kg/ha)

INPUT DATA AND YIELD ESTIMATES FOR SOYBEANS (ALTERED CLIMATIC REGIME)

SCENARIO: B CROP: SOYBEANS MAP UNIT: C1002 AWHC: 150 mm

PLANTING PERIOD

		APR 7- APR 13	APR 14- APR 20	APR 21- APR 27	APR 28- MAY 4	MAY 5- MAY 11	MAY 12- MAY 18
HARVEST PERIOD 1 OCT 18 - OCT 31	GP	130	130	130	130	130	130
	CFY	3206	3206	3206	3206	3206	3206
	PREC	342	340	337	332	328	323
	PE	479	484	486	485	481	474
	SMDS	13	6	1	-3	-3	-1
	MSF	0.87	0.85	0.83	0.82	0.82	0.83
	AY	2510	2441	2392	2355	2355	2372
	FAY	1883	1831	1794	1766	1766	1779
HARVEST PERIOD 2 NOV 1 - NOV 21	GP	130	130	130	130	130	130
	CFY	3206	3206	3206	3206	3206	3206
	PREC	342	340	337	332	328	323
	PE	479	484	486	485	481	474
	SMDS	13	6	1	-3	-3	-1
	MSF	0.87	0.85	0.83	0.82	0.82	0.83
	AY	2510	2441	2392	2355	2355	2372
	FAY	1883	1831	1794	1766	1766	1779
HARVEST PERIOD 3 NOV 22 - DEC 12	GP	130	130	130	130	130	130
	CFY	3206	3206	3206	3206	3206	3206
	PREC	342	340	337	332	328	323
	PE	479	484	486	485	481	474
	SMDS	13	6	1	-3	-3	-1
	MSF	0.87	0.85	0.83	0.82	0.82	0.83
	AY	2510	2441	2392	2355	2355	2372
	FAY	1883	1831	1794	1766	1766	1779

NOTE: GP = Growing Period (days)
 CFY = Constraint-Free Yield (kg/ha)
 PREC = Precipitation (mm)
 PE = Potential Evapotranspiration (mm)
 SMDS = Soil Moisture Deficit or Surplus (cm)
 MSF = Moisture Stress Factor
 AY = Attainable Yield (kg/ha)
 FAY = Farm Attainable Yield (kg/ha)

INPUT DATA AND YIELD ESTIMATES FOR WINTER WHEAT (CURRENT CLIMATIC REGIME)

SCENARIO: C CROP: WINTER WHEAT MAP UNIT: C1002 AWHC: 150 mm

 PLANTING PERIOD
 SEPT 15- SEPT 29-
 SEPT 28 OCT 19

HARVEST PERIOD	GP	100	100
JUNE 14 - JULY 20	CFY	4446	4446
	PREC	247	247
	PE	370	370
	SMDS	27	27
	MSF	0.92	0.92
	AY	4605	4605
	FAY	3454	3454

INPUT DATA AND YIELD ESTIMATES FOR WINTER WHEAT (ALTERED CLIMATIC REGIME)

SCENARIO: B CROP: WINTER WHEAT MAP UNIT: C1002 AWHC: 150 mm

 PLANTING PERIOD
 OCT 18- NOV 1-
 OCT 31 NOV 21

HARVEST PERIOD	GP	100	100
JUNE 1 - JULY 6	CFY	3571	3571
	PREC	266	266
	PE	366	366
	SMDS	50	50
	MSF	1.00	1.00
	AY	4003	4003
	FAY	3002	3002

NOTE: GP = Growing Period (days)
 CFY = Constraint-Free Yield (kg/ha)
 PREC = Precipitation (mm)
 PE = Potential Evapotranspiration (mm)
 SMDS = Soil Moisture Deficit or Surplus (cm)
 MSF = Moisture Stress Factor
 AY = Attainable Yield (kg/ha)
 FAY = Farm Attainable Yield (kg/ha)

APPENDIX 4: PROCEDURES FOR ESTIMATING ATTAINABLE YIELDS

$$Y_{ijr}^A = Y_{ir}^{CF} \cdot MSF_{ijr} \cdot WP_{ir} \cdot D_i \cdot Z_j \cdot M_i \quad (1)$$

$$MSF_{ijr} = 1 - [ky_i \cdot (SMDS_{ijr} + a_i)/b_i] \quad (2)$$

$$SMDS_{ijr} = AW_{jr} + PREC_{ir} - PE_{ir} \quad (3)$$

where:

Y_{ijr}^A = Attainable dry weight yield (kg/ha) for crop i on land type j in region r

Y_{ir}^{CF} = Constraint-free dry matter yield (kg/ha) for crop i in region r

MSF_{ijr} = Moisture stress factor for crop i on land type j in region r

WP_{ir} = Workability parameter for crop i in region r

D_i = Dry matter to dry weight conversion coefficient for crop i

Z_j = Deflation coefficient for poor soil aeration on land type j

M_i = Deflation coefficient for average management practices for crop i

ky_i = Seasonal yield response coefficient for crop i to water stress

$SMDS_{ijr}$ = Soil moisture deficit or surplus (cm) for crop i on land type j in region r

a_i & b_i = Coefficients to normalize for excess or deficit stress moisture conditions for crop i

AW_{jr} = Plant-available water at the onset of the growing season for land type j in region r

$PREC_{ir}$ = Total precipitation during crop i's growing period in region r

PE_{ir} = Potential evapotranspiration during crop i's growing period in region r

Constraint-free dry matter yields for each crop in each region (Y_{CF}^{ir}) given the three climatic scenarios are summarized elsewhere (LEG, 1985, Appendix 6).¹ All other data inputs (MSF_{ijr} , WP_{ir} , D_i , etc.) used to estimate the effects of climatic change on $Y_{A_{ijr}}$ are presented in Appendix 5.

¹ Land Evaluation Group. 1985. Socio-economic assessment of the implications of climatic change for food production in Ontario. Publication No. LEG-22. University School of Rural Planning and Development, University of Guelph. Guelph.

NOTE: For fodder corn and potatoes, attainable yields are reported in fresh weight rather than dry weight. For these crops, D_i represents a dry matter to fresh weight conversion coefficient.

APPENDIX 5: DATA INPUTS FOR ESTIMATING THE EFFECTS OF CLIMATIC CHANGE AND VARIABILITY IN PRECIPITATION ON CROP YIELDS

Notations and Definitions

Land Types

Notation Used in Appendix	Biophysical Characteristics	Notation Used in Text
1	Well-drained loamy soils, relatively level topography	A
2	Fine-textured clays, moderately well to well-drained	B
3	Coarse-textured sands or gravels, well to excessively well-drained	C ¹
4	Imperfectly drained soils which have been tiled	D
5	Imperfectly drained soils which have not been tiled, and all poorly to very poorly drained soils	E
6	Extremely stony or extremely shallow soils	F
7	Well-drained loamy soils, rolling to hilly topography	G
8	Shallow soils, well to excessively-well drained	C ¹

¹ Land type C is a combination of land types 3 and 8.

Regions

NO = Northern Ontario	SCO = South Central Ontario
EO = Eastern Ontario	WO = Western Ontario
CO = Central Ontario	SWO = South Western Ontario

Scenarios

Defined in Land Evaluation Group (1985, Appendix 6)¹

Constraint-Free Dry Matter Yields

Listed in Land Evaluation Group (1985, Appendix 6)

¹ Land Evaluation Group. 1985. Socio-economic assessment of the implications of climatic change for food production in Ontario. Publication No. LEG-22. University School of Rural Planning and Development, University of Guelph. Guelph.

APPENDIX 5 Continued

Moisture Stress Factors for Current Thermal Regime: Average Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	1.00	1.00	1.00	1.00	1.00	0.88	0.88
	2	0.72	0.72	0.83	0.75	0.79	1.00	1.00
	3	0.72	0.72	0.83	0.75	0.79	1.00	1.00
	4	0.89	0.89	0.79	0.90	0.85	0.52	0.52
	5	0.68	0.68	0.58	0.71	0.65	0.32	0.32
	7	1.00	1.00	1.00	1.00	1.00	0.88	0.88
	8	0.83	0.83	0.94	0.85	0.89	1.00	1.00
	1	1.00	1.00	0.96	0.90	0.94	1.00	1.00
CO	2	0.70	0.70	0.62	0.58	0.62	0.94	0.94
	3	0.70	0.70	0.62	0.58	0.62	0.94	0.94
	4	0.91	0.91	1.00	1.00	1.00	0.69	0.69
	5	0.69	0.69	0.80	0.88	0.83	0.50	0.50
	7	1.00	1.00	0.96	0.90	0.94	1.00	1.00
	8	0.81	0.81	0.72	0.68	0.71	1.00	1.00
	1	0.91	0.91	0.94	0.87	0.95	1.00	1.00
	2	0.55	0.55	0.60	0.55	0.62	0.95	0.95
WO	3	0.55	0.55	0.60	0.55	0.62	0.95	0.95
	4	1.00	1.00	1.00	1.00	1.00	0.69	0.69
	5	0.84	0.84	0.82	0.91	0.82	0.49	0.49
	7	0.91	0.91	0.94	0.87	0.95	1.00	1.00
	8	0.66	0.66	0.70	0.65	0.72	1.00	1.00
	1	1.00	1.00	1.00	1.00	1.00	0.96	0.96
	2	0.65	0.65	0.74	0.70	0.71	1.00	1.00
	3	0.65	0.65	0.74	0.70	0.71	1.00	1.00
EO	4	0.95	0.95	0.88	0.96	0.93	0.60	0.60
	5	0.74	0.74	0.68	0.77	0.73	0.40	0.40
	7	1.00	1.00	1.00	1.00	1.00	0.96	0.96
	8	0.76	0.76	0.84	0.79	0.81	1.00	1.00
	1	0.83	0.83	0.89	0.82	0.92	1.00	1.00
	2	0.48	0.48	0.55	0.51	0.60	0.92	0.92
	3	0.48	0.48	0.55	0.51	0.60	0.92	0.92
	4	1.00	1.00	1.00	1.00	1.00	0.71	0.71
SCO	5	0.92	0.92	0.87	0.96	0.85	0.52	0.52
	7	0.83	0.83	0.89	0.82	0.92	1.00	1.00
	8	0.58	0.58	0.65	0.60	0.69	1.00	1.00
	1	0.83	0.83	0.86	0.78	0.91	1.00	1.00
	2	0.47	0.47	0.52	0.47	0.58	0.91	0.91
	3	0.47	0.47	0.52	0.47	0.58	0.91	0.91
	4	1.00	1.00	1.00	1.00	1.00	0.73	0.73
	5	0.92	0.92	0.90	1.00	0.86	0.53	0.53
SWO	7	0.83	0.83	0.86	0.78	0.91	1.00	1.00
	8	0.58	0.58	0.62	0.56	0.68	1.00	1.00

NOTE: Land type 6 is physically unsuitable for all crops except pasture and therefore a moisture stress factor is not presented for this land type under all climatic scenarios.

APPENDIX 5 Continued

Moisture Stress Factors for Current Thermal Regime: Low Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	0.71	0.71	0.82	0.74	0.83	1.00	1.00
	2	0.35	0.35	0.48	0.43	0.50	0.83	0.83
	3	0.35	0.35	0.48	0.43	0.50	0.83	0.83
	4	1.00	1.00	1.00	1.00	1.00	0.81	0.81
	5	1.00	1.00	0.94	1.00	0.94	0.61	0.61
	7	0.71	0.71	0.82	0.74	0.83	1.00	1.00
	8	0.46	0.46	0.58	0.52	0.60	0.93	0.93
	1	0.71	0.71	0.67	0.61	0.73	1.00	1.00
CO	2	0.35	0.35	0.32	0.29	0.40	0.73	0.73
	3	0.35	0.35	0.32	0.29	0.40	0.73	0.73
	4	1.00	1.00	1.00	0.95	1.00	0.91	0.91
	5	1.00	1.00	1.00	1.00	1.00	0.71	0.71
	7	0.71	0.71	0.67	0.61	0.73	1.00	1.00
	8	0.46	0.46	0.43	0.39	0.50	0.83	0.83
	1	0.50	0.50	0.61	0.55	0.71	1.00	1.00
	2	0.15	0.15	0.27	0.23	0.38	0.71	0.71
WO	3	0.15	0.15	0.27	0.23	0.38	0.71	0.71
	4	0.90	0.90	0.99	0.89	1.00	0.93	0.93
	5	1.00	1.00	1.00	1.00	1.00	0.73	0.73
	7	0.50	0.50	0.61	0.55	0.71	1.00	1.00
	8	0.25	0.25	0.37	0.33	0.48	0.81	0.81
	1	0.69	0.69	0.79	0.72	0.83	1.00	1.00
	2	0.33	0.33	0.45	0.41	0.50	0.83	0.83
	3	0.33	0.33	0.45	0.41	0.50	0.83	0.83
EO	4	1.00	1.00	1.00	1.00	1.00	0.81	0.81
	5	1.00	1.00	0.97	1.00	0.94	0.62	0.62
	7	0.69	0.69	0.79	0.72	0.83	1.00	1.00
	8	0.44	0.44	0.55	0.50	0.60	0.92	0.92
	1	0.44	0.44	0.57	0.50	0.69	1.00	1.00
	2	0.08	0.08	0.23	0.19	0.36	0.69	0.69
	3	0.08	0.08	0.23	0.19	0.36	0.69	0.69
	4	0.83	0.83	0.95	0.85	1.00	0.95	0.95
SCO	5	1.00	1.00	1.00	1.00	1.00	0.75	0.75
	7	0.44	0.44	0.57	0.50	0.69	1.00	1.00
	8	0.19	0.19	0.33	0.28	0.46	0.79	0.79
	1	0.38	0.38	0.52	0.45	0.66	0.99	0.99
	2	0.02	0.02	0.18	0.14	0.33	0.66	0.66
	3	0.02	0.02	0.18	0.14	0.33	0.66	0.66
	4	0.77	0.77	0.90	0.80	1.00	0.98	0.98
	5	0.98	0.98	1.00	0.98	1.00	0.78	0.78
SWO	7	0.38	0.38	0.52	0.45	0.66	0.99	0.99
	8	0.13	0.13	0.28	0.23	0.43	0.76	0.76

APPENDIX 5 Continued

Moisture Stress Factors for Current Thermal Regime: High Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	0.92	0.92	0.82	0.93	0.92	0.60	0.60
	2	1.00	1.00	1.00	1.00	1.00	0.92	0.92
	3	1.00	1.00	1.00	1.00	1.00	0.92	0.92
	4	0.53	0.53	0.44	0.59	0.56	0.23	0.23
	5	0.31	0.31	0.24	0.40	0.37	0.04	0.04
	7	0.92	0.92	0.82	0.93	0.92	0.60	0.60
	8	1.00	1.00	1.00	1.00	1.00	0.83	0.83
	1	0.91	0.91	1.00	1.00	1.00	0.81	0.81
CO	2	1.00	1.00	0.94	0.91	0.86	1.00	1.00
	3	1.00	1.00	0.94	0.91	0.86	1.00	1.00
	4	0.52	0.52	0.68	0.75	0.78	0.45	0.45
	5	0.30	0.30	0.47	0.56	0.58	0.25	0.25
	7	0.91	0.91	1.00	1.00	1.00	0.81	0.81
	8	1.00	1.00	1.00	1.00	0.96	1.00	1.00
	1	1.00	1.00	1.00	1.00	1.00	0.87	0.87
	2	0.86	0.86	0.85	0.80	0.81	1.00	1.00
WO	3	0.86	0.86	0.85	0.80	0.81	1.00	1.00
	4	0.74	0.74	0.78	0.86	0.83	0.50	0.50
	5	0.53	0.53	0.57	0.67	0.64	0.31	0.31
	7	1.00	1.00	1.00	1.00	1.00	0.87	0.87
	8	0.97	0.97	0.95	0.89	0.90	1.00	1.00
	1	0.99	0.99	0.95	0.99	1.00	0.73	0.73
	2	1.00	1.00	1.00	1.00	0.94	1.00	1.00
	3	1.00	1.00	1.00	1.00	0.94	1.00	1.00
EO	4	0.60	0.60	0.57	0.65	0.69	0.37	0.37
	5	0.39	0.39	0.37	0.46	0.50	0.17	0.17
	7	0.99	0.99	0.95	0.99	1.00	0.73	0.73
	8	1.00	1.00	1.00	1.00	1.00	0.96	0.96
	1	1.00	1.00	1.00	1.00	1.00	0.90	0.90
	2	0.76	0.76	0.78	0.74	0.77	1.00	1.00
	3	0.76	0.76	0.78	0.74	0.77	1.00	1.00
	4	0.84	0.84	0.84	0.92	0.87	0.54	0.54
SCO	5	0.63	0.63	0.63	0.73	0.67	0.34	0.34
	7	1.00	1.00	1.00	1.00	1.00	0.90	0.90
	8	0.87	0.87	0.89	0.83	0.87	1.00	1.00
	1	1.00	1.00	1.00	1.00	1.00	0.91	0.91
	2	0.79	0.79	0.76	0.70	0.76	1.00	1.00
	3	0.79	0.79	0.76	0.70	0.76	1.00	1.00
	4	0.82	0.82	0.87	0.95	0.88	0.55	0.55
	5	0.60	0.60	0.66	0.76	0.68	0.36	0.36
SWO	7	1.00	1.00	1.00	1.00	1.00	0.91	0.91
	8	0.90	0.90	0.86	0.80	0.86	1.00	1.00

APPENDIX 5 Continued

Moisture Stress Factors for Future Thermal Regime: Average Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	1.00	1.00	1.00	0.98	1.00	0.96	0.96
	2	0.74	0.74	0.71	0.67	0.71	1.00	1.00
	3	0.74	0.74	0.71	0.67	0.71	1.00	1.00
	4	0.86	0.86	0.91	0.99	0.93	0.60	0.60
	5	0.65	0.65	0.70	0.80	0.73	0.40	0.40
	7	1.00	1.00	1.00	0.98	1.00	0.96	0.96
	8	0.85	0.85	0.82	0.76	0.81	1.00	1.00
		0.81	0.81	0.81	0.73	0.87	1.00	1.00
CO	1	0.81	0.81	0.81	0.73	0.87	1.00	1.00
	2	0.46	0.46	0.46	0.42	0.54	0.87	0.87
	3	0.46	0.46	0.46	0.42	0.54	0.87	0.87
	4	1.00	1.00	1.00	1.00	1.00	0.77	0.77
	5	0.94	0.94	0.95	1.00	0.90	0.57	0.57
	7	0.81	0.81	0.81	0.73	0.87	1.00	1.00
	8	0.56	0.56	0.57	0.51	0.64	0.97	0.97
		0.74	0.74	0.82	0.72	0.92	1.00	1.00
WO	1	0.74	0.74	0.82	0.72	0.92	1.00	1.00
	2	0.38	0.38	0.47	0.41	0.59	0.92	0.92
	3	0.38	0.38	0.47	0.41	0.59	0.92	0.92
	4	1.00	1.00	1.00	1.00	1.00	0.72	0.72
	5	1.00	1.00	0.94	1.00	0.85	0.52	0.52
	7	0.74	0.74	0.82	0.72	0.92	1.00	1.00
	8	0.49	0.49	0.58	0.50	0.69	1.00	1.00
		0.86	0.86	0.85	0.77	0.92	1.00	1.00
EO	1	0.86	0.86	0.85	0.77	0.92	1.00	1.00
	2	0.51	0.51	0.51	0.46	0.59	0.92	0.92
	3	0.51	0.51	0.51	0.46	0.59	0.92	0.92
	4	1.00	1.00	1.00	1.00	1.00	0.72	0.72
	5	0.89	0.89	0.91	1.00	0.85	0.52	0.52
	7	0.86	0.86	0.85	0.77	0.92	1.00	1.00
	8	0.61	0.61	0.61	0.55	0.69	1.00	1.00
		0.69	0.69	0.79	0.70	0.91	1.00	1.00
SCO	1	0.69	0.69	0.79	0.70	0.91	1.00	1.00
	2	0.33	0.33	0.45	0.38	0.59	0.91	0.91
	3	0.33	0.33	0.45	0.38	0.59	0.91	0.91
	4	1.00	1.00	1.00	1.00	1.00	0.72	0.72
	5	1.00	1.00	0.97	1.00	0.86	0.53	0.53
	7	0.69	0.69	0.79	0.70	0.91	1.00	1.00
	8	0.44	0.44	0.55	0.48	0.68	1.00	1.00
		0.65	0.65	0.79	0.69	0.93	1.00	1.00
SWO	1	0.65	0.65	0.79	0.69	0.93	1.00	1.00
	2	0.29	0.29	0.45	0.38	0.60	0.93	0.93
	3	0.29	0.29	0.45	0.38	0.60	0.93	0.93
	4	1.00	1.00	1.00	1.00	1.00	0.71	0.71
	5	1.00	1.00	0.97	1.00	0.84	0.51	0.51
	7	0.65	0.65	0.79	0.69	0.93	1.00	1.00
	8	0.40	0.40	0.55	0.47	0.70	1.00	1.00

APPENDIX 5 Continued

Moisture Stress Factors for Future Thermal Regime: Low Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	0.70	0.70	0.75	0.68	0.82	1.00	1.00
	2	0.34	0.34	0.41	0.37	0.49	0.82	0.82
	3	0.34	0.34	0.41	0.37	0.49	0.82	0.82
	4	1.00	1.00	1.00	1.00	1.00	0.82	0.82
	5	1.00	1.00	1.00	1.00	0.95	0.63	0.63
	7	0.70	0.70	0.75	0.68	0.82	1.00	1.00
	8	0.45	0.45	0.51	0.46	0.59	0.91	0.91
		0.42	0.42	0.53	0.46	0.67	1.00	1.00
CO	1	0.42	0.42	0.53	0.46	0.67	1.00	1.00
	2	0.06	0.06	0.19	0.15	0.34	0.67	0.67
	3	0.06	0.06	0.19	0.15	0.34	0.67	0.67
	4	0.81	0.81	0.91	0.81	1.00	0.97	0.97
	5	1.00	1.00	1.00	1.00	1.00	0.77	0.77
	7	0.42	0.42	0.53	0.46	0.67	1.00	1.00
	8	0.17	0.17	0.29	0.24	0.44	0.77	0.77
		0.19	0.19	0.44	0.35	0.64	0.97	0.97
WO	1	0.19	0.19	0.44	0.35	0.64	0.97	0.97
	2	0.00	0.00	0.10	0.03	0.32	0.64	0.64
	3	0.00	0.00	0.10	0.03	0.32	0.64	0.64
	4	0.59	0.59	0.82	0.69	1.00	0.99	0.99
	5	0.80	0.80	1.00	0.88	1.00	0.80	0.80
	7	0.19	0.19	0.44	0.35	0.64	0.97	0.97
	8	0.00	0.00	0.20	0.13	0.41	0.74	0.74
		0.45	0.45	0.56	0.49	0.71	1.00	1.00
EO	1	0.45	0.45	0.56	0.49	0.71	1.00	1.00
	2	0.09	0.09	0.22	0.17	0.38	0.71	0.71
	3	0.09	0.09	0.22	0.17	0.38	0.71	0.71
	4	0.84	0.84	0.94	0.83	1.00	0.93	0.93
	5	1.00	1.00	1.00	1.00	1.00	0.73	0.73
	7	0.45	0.45	0.56	0.49	0.71	1.00	1.00
	8	0.20	0.20	0.32	0.27	0.48	0.81	0.81
		0.14	0.14	0.41	0.32	0.64	0.96	0.96
SCO	1	0.14	0.14	0.41	0.32	0.64	0.96	0.96
	2	0.00	0.00	0.07	0.01	0.31	0.64	0.64
	3	0.00	0.00	0.07	0.01	0.31	0.64	0.64
	4	0.54	0.54	0.79	0.67	1.00	1.00	1.00
	5	0.75	0.75	1.00	0.86	1.00	0.81	0.81
	7	0.14	0.14	0.41	0.32	0.64	0.96	0.96
	8	0.00	0.00	0.17	0.10	0.41	0.73	0.73
		0.11	0.11	0.42	0.32	0.65	0.98	0.98
SWO	1	0.11	0.11	0.42	0.32	0.65	0.98	0.98
	2	0.00	0.00	0.07	0.01	0.32	0.65	0.65
	3	0.00	0.00	0.07	0.01	0.32	0.65	0.65
	4	0.50	0.50	0.79	0.67	1.00	0.99	0.99
	5	0.71	0.71	1.00	0.86	1.00	0.79	0.79
	7	0.11	0.11	0.42	0.32	0.65	0.98	0.98
	8	0.00	0.00	0.18	0.10	0.42	0.75	0.75

APPENDIX 5 Continued

Moisture Stress Factors for Future Thermal Regime: High Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	0.67	0.67	0.84	0.89	0.96	0.63	0.63
	2	1.00	1.00	1.00	1.00	1.00	0.96	0.96
	3	1.00	1.00	1.00	1.00	1.00	0.96	0.96
	4	0.28	0.28	0.46	0.55	0.60	0.27	0.27
	5	0.06	0.06	0.26	0.36	0.40	0.07	0.07
	7	0.67	0.67	0.84	0.89	0.96	0.63	0.63
	8	0.92	0.92	1.00	1.00	1.00	0.86	0.86
	1	1.00	1.00	0.96	0.88	0.99	1.00	1.00
CO	2	0.68	0.68	0.62	0.57	0.66	0.99	0.99
	3	0.68	0.68	0.62	0.57	0.66	0.99	0.99
	4	0.93	0.93	1.00	1.00	0.98	0.65	0.65
	5	0.71	0.71	0.80	0.90	0.78	0.45	0.45
	7	1.00	1.00	0.96	0.88	0.99	1.00	1.00
	8	0.79	0.79	0.72	0.66	0.76	1.00	1.00
	1	1.00	1.00	1.00	0.96	1.00	0.90	0.90
	2	0.73	0.73	0.72	0.65	0.77	1.00	1.00
WO	3	0.73	0.73	0.72	0.65	0.77	1.00	1.00
	4	0.88	0.88	0.91	1.00	0.87	0.54	0.54
	5	0.66	0.66	0.70	0.82	0.67	0.34	0.34
	7	1.00	1.00	1.00	0.96	1.00	0.90	0.90
	8	0.84	0.84	0.82	0.74	0.87	1.00	1.00
	1	1.00	1.00	1.00	1.00	1.00	0.87	0.87
	2	0.91	0.91	0.79	0.74	0.80	1.00	1.00
	3	0.91	0.91	0.79	0.74	0.80	1.00	1.00
EO	4	0.69	0.69	0.83	0.92	0.84	0.51	0.51
	5	0.48	0.48	0.62	0.73	0.64	0.31	0.31
	7	1.00	1.00	1.00	1.00	1.00	0.87	0.87
	8	1.00	1.00	0.90	0.83	0.90	1.00	1.00
	1	1.00	1.00	1.00	0.94	1.00	0.91	0.91
	2	0.68	0.68	0.70	0.63	0.76	1.00	1.00
	3	0.68	0.68	0.70	0.63	0.76	1.00	1.00
	4	0.93	0.93	0.93	1.00	0.87	0.55	0.55
SCO	5	0.71	0.71	0.72	0.84	0.68	0.35	0.35
	7	1.00	1.00	1.00	0.94	1.00	0.91	0.91
	8	0.79	0.79	0.80	0.72	0.86	1.00	1.00
	1	1.00	1.00	1.00	0.93	1.00	0.89	0.89
	2	0.65	0.65	0.70	0.62	0.78	1.00	1.00
	3	0.65	0.65	0.70	0.62	0.78	1.00	1.00
	4	0.96	0.96	0.93	1.00	0.86	0.53	0.53
	5	0.74	0.74	0.72	0.85	0.66	0.33	0.33
SWO	7	1.00	1.00	1.00	0.93	1.00	0.89	0.89
	8	0.76	0.76	0.80	0.71	0.88	1.00	1.00

APPENDIX 5 Continued

Workability Parameters

Region	Scenario	Fodder Corn	Grain Corn	Soybeans	Potatoes	Wheat	Barley	Oats
NO	Cur	0.50	0.05	0.00	0.23	0.23	0.78	0.67
	Fut	0.70	0.85	0.76	0.95	0.95	0.96	0.93
CO	Cur	0.70	0.64	0.64	0.67	0.78	0.76	0.75
	Fut	0.70	0.85	0.76	0.95	0.95	0.96	0.93
WO	Cur	0.60	0.76	0.73	0.95	0.95	0.96	0.94
	Fut	0.70	0.85	0.76	0.95	0.95	0.96	0.93
EO	Cur	0.60	0.57	0.57	0.72	0.90	0.97	0.74
	Fut	0.70	0.85	0.76	0.95	0.95	0.96	0.93
SCO	Cur	0.70	0.81	0.62	0.95	0.95	0.96	0.95
	Fut	0.70	0.85	0.76	0.95	0.95	0.96	0.93
SWO	Cur	0.70	0.85	0.76	0.95	0.95	0.96	0.93
	Fut	0.70	0.85	0.76	0.95	0.95	0.96	0.93

APPENDIX 5 Continued

Dry Matter to Dry Weight Conversion Coefficients

Crop	Conversion Coefficient
Grain Corn	1.18
Soybeans	1.18
Wheat	1.18
Hay	1.27
Barley	1.18
Oats	1.18

Dry Matter to Fresh Weight Conversion Coefficients

Crop	Conversion Coefficient
Fodder Corn	2.50
Potatoes	3.12

Plant-Available Water Estimates and Soil Aeration Coefficients

Land Type	Plant-Available Water (cm) at GSS	Soil Aeration Coefficient
1	15	1.00
2	5	1.00
4	26	0.72
5	32	0.45
6	2	1.00
7	15	1.00
8	8	1.00

Farm Management Coefficients

Yields consistent with average management conditions and current technologies are approximately 75 per cent of attainable yield levels that are estimated by the crop productivity model outlined in Appendix 4.

APPENDIX 5 Continued

Seasonal Yield Response and Normalizing Coefficients

Crop	Optimum SMDS	Seasonal Crop Yield Response Factor (ky)	DMSF		EMS F		MSF = 1.0
			a	b	a	b	
Fodder Corn	+13	1.25	- 8	-35	-18	35	+8<SMDS<+18
Grain Corn	+13	1.25	- 8	-35	-18	35	+8<SMDS<+18
Soybeans	+10	1.20	- 5	-35	-15	35	+5<SMDS<+15
Potatoes	+13	1.10	- 8	-35	-18	35	+8<SMDS<+18
Wheat	+10	1.15	- 5	-35	-15	35	+5<SMDS<+15
Hay Crops	+26	1.10	-21	-35	-31	35	+21<SMDS<+31
Barley	0	1.15	5	-35	-5	35	-5<SMDS< +5
Oats	0	1.15	5	-35	-5	35	-5<SMDS< +5

DMSF: Deficit Moisture Stress Factor
EMS F: Excess Moisture Stress Factor

APPENDIX 5 Continued

Soil Moisture Deficit or Surplus (cm) for Current Thermal Regime: Average Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	10.1	10.1	10.1	10.1	8.7	8.7	8.7
	2	0.1	0.1	0.1	0.1	-1.3	-1.3	-1.3
	3	0.1	0.1	0.1	0.1	-1.3	-1.3	-1.3
	4	21.1	21.1	21.1	21.1	19.7	19.7	19.7
	5	27.1	27.1	27.1	27.1	25.7	25.7	25.7
	7	10.1	10.1	10.1	10.1	8.7	8.7	8.7
	8	3.1	3.1	3.1	3.1	1.7	1.7	1.7
	1	9.6	9.6	3.8	4.7	3.3	3.3	3.3
CO	2	-0.4	-0.4	-6.2	-5.3	-6.7	-6.7	-6.7
	3	-0.4	-0.4	-6.2	-5.3	-6.7	-6.7	-6.7
	4	20.6	20.6	14.8	15.7	14.3	14.3	14.3
	5	26.6	26.6	20.8	21.7	20.3	20.3	20.3
	7	9.6	9.6	3.8	4.7	3.3	3.3	3.3
	8	2.6	2.6	-3.2	-2.3	-3.7	-3.7	-3.7
	1	5.5	5.5	3.2	3.8	3.5	3.5	3.5
	2	-4.5	-4.5	-6.8	-6.2	-6.5	-6.5	-6.5
WO	3	-4.5	-4.5	-6.8	-6.2	-6.5	-6.5	-6.5
	4	16.5	16.5	14.2	14.8	14.5	14.5	14.5
	5	22.5	22.5	20.2	20.8	20.5	20.5	20.5
	7	5.5	5.5	3.2	3.8	3.5	3.5	3.5
	8	-1.5	-1.5	-3.8	-3.2	-3.5	-3.5	-3.5
	1	8.3	8.3	7.4	8.3	6.2	6.2	6.2
	2	-1.7	-1.7	-2.6	-1.7	-3.8	-3.8	-3.8
	3	-1.7	-1.7	-2.6	-1.7	-3.8	-3.8	-3.8
EO	4	19.3	19.3	18.4	19.3	17.2	17.2	17.2
	5	25.3	25.3	24.4	25.3	23.2	23.2	23.2
	7	8.3	8.3	7.4	8.3	6.2	6.2	6.2
	8	1.3	1.3	0.4	1.3	-0.8	-0.8	-0.8
	1	3.3	3.3	1.9	2.3	2.7	2.7	2.7
	2	-6.7	-6.7	-8.1	-7.7	-7.3	-7.3	-7.3
	3	-6.7	-6.7	-8.1	-7.7	-7.3	-7.3	-7.3
	4	14.3	14.3	12.9	13.3	13.7	13.7	13.7
SCO	5	20.3	20.3	18.9	19.3	19.7	19.7	19.7
	7	3.3	3.3	1.9	2.3	2.7	2.7	2.7
	8	-3.7	-3.7	-5.1	-4.7	-4.3	-4.3	-4.3
	1	3.2	3.2	1.0	1.1	2.3	2.3	2.3
	2	-6.8	-6.8	-9.0	-8.9	-7.7	-7.7	-7.7
	3	-6.8	-6.8	-9.0	-8.9	-7.7	-7.7	-7.7
	4	14.2	14.2	12.0	12.1	13.3	13.3	13.3
	5	20.2	20.2	18.0	18.1	19.3	19.3	19.3
SWO	7	3.2	3.2	1.0	1.1	2.3	2.3	2.3
	8	-3.8	-3.8	-6.0	-5.9	-4.7	-4.7	-4.7

APPENDIX 5 Continued

Soil Moisture Deficit or Surplus (cm) for Current Thermal Regime: Low Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1
	2	-10.2	-10.2	-10.2	-10.2	-10.1	-10.1	-10.1
	3	-10.2	-10.2	-10.2	-10.2	-10.1	-10.1	-10.1
	4	10.8	10.8	10.8	10.8	10.9	10.9	10.9
	5	16.8	16.8	16.8	16.8	16.9	16.9	16.9
	7	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1
	8	-7.2	-7.2	-7.2	-7.2	-7.1	-7.1	-7.1
		-0.1	-0.1	-4.7	-4.5	-3.2	-3.2	-3.2
CO	1	-0.1	-0.1	-4.7	-4.5	-3.2	-3.2	-3.2
	2	-10.1	-10.1	-14.7	-14.5	-13.2	-13.2	-13.2
	3	-10.1	-10.1	-14.7	-14.5	-13.2	-13.2	-13.2
	4	10.9	10.9	6.3	6.5	7.8	7.8	7.8
	5	16.9	16.9	12.3	12.5	13.8	13.8	13.8
	7	-0.1	-0.1	-4.7	-4.5	-3.2	-3.2	-3.2
	8	-7.1	-7.1	-11.7	-11.5	-10.2	-10.2	-10.2
		-5.9	-5.9	-6.3	-6.4	-3.8	-3.8	-3.8
WO	1	-5.9	-5.9	-6.3	-6.4	-3.8	-3.8	-3.8
	2	-15.9	-15.9	-16.3	-16.4	-13.8	-13.8	-13.8
	3	-15.9	-15.9	-16.3	-16.4	-13.8	-13.8	-13.8
	4	5.1	5.1	4.7	4.6	7.2	7.2	7.2
	5	11.1	11.1	10.7	10.6	13.2	13.2	13.2
	7	-5.9	-5.9	-6.3	-6.4	-3.8	-3.8	-3.8
	8	-12.9	-12.9	-13.3	-13.4	-10.8	-10.8	-10.8
		-0.8	-0.8	-1.1	-0.8	-0.3	-0.3	-0.3
EO	1	-0.8	-0.8	-1.1	-0.8	-0.3	-0.3	-0.3
	2	-10.8	-10.8	-11.1	-10.8	-10.3	-10.3	-10.3
	3	-10.8	-10.8	-11.1	-10.8	-10.3	-10.3	-10.3
	4	10.2	10.2	9.9	10.2	10.7	10.7	10.7
	5	16.2	16.2	15.9	16.2	16.7	16.7	16.7
	7	-0.8	-0.8	-1.1	-0.8	-0.3	-0.3	-0.3
	8	-7.8	-7.8	-8.1	-7.8	-7.3	-7.3	-7.3
		-7.8	-7.8	-7.5	-7.8	-4.5	-4.5	-4.5
SCO	1	-7.8	-7.8	-7.5	-7.8	-4.5	-4.5	-4.5
	2	-17.8	-17.8	-17.5	-17.8	-14.5	-14.5	-14.5
	3	-17.8	-17.8	-17.5	-17.8	-14.5	-14.5	-14.5
	4	3.2	3.2	3.5	3.2	6.5	6.5	6.5
	5	9.2	9.2	9.5	9.2	12.5	12.5	12.5
	7	-7.8	-7.8	-7.5	-7.8	-4.5	-4.5	-4.5
	8	-14.8	-14.8	-14.5	-14.8	-11.5	-11.5	-11.5
		-9.5	-9.5	-8.9	-9.5	-5.3	-5.3	-5.3
SWO	1	-9.5	-9.5	-8.9	-9.5	-5.3	-5.3	-5.3
	2	-19.5	-19.5	-18.9	-19.5	-15.3	-15.3	-15.3
	3	-19.5	-19.5	-18.9	-19.5	-15.3	-15.3	-15.3
	4	1.5	1.5	2.1	1.5	5.7	5.7	5.7
	5	7.5	7.5	8.1	7.5	11.7	11.7	11.7
	7	-9.5	-9.5	-8.9	-9.5	-5.3	-5.3	-5.3
	8	-16.5	-16.5	-15.9	-16.5	-12.3	-12.3	-12.3

APPENDIX 5 Continued

Soil Moisture Deficit or Surplus (cm) for Current Thermal Regime: High Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	20.2	20.2	20.2	20.2	17.3	17.3	17.3
	2	10.2	10.2	10.2	10.2	7.3	7.3	7.3
	3	10.2	10.2	10.2	10.2	7.3	7.3	7.3
	4	31.2	31.2	31.2	31.2	28.3	28.3	28.3
	5	37.2	37.2	37.2	37.2	34.3	34.3	34.3
	7	20.2	20.2	20.2	20.2	17.3	17.3	17.3
	8	13.2	13.2	13.2	13.2	10.3	10.3	10.3
CO	1	20.5	20.5	13.4	15.0	10.7	10.7	10.7
	2	10.5	10.5	3.4	5.0	0.7	0.7	0.7
	3	10.5	10.5	3.4	5.0	0.7	0.7	0.7
	4	31.5	31.5	24.4	26.0	21.7	21.7	21.7
	5	37.5	37.5	30.4	32.0	27.7	27.7	27.7
	7	20.5	20.5	13.4	15.0	10.7	10.7	10.7
	8	13.5	13.5	6.4	8.0	3.7	3.7	3.7
WO	1	14.2	14.2	10.5	11.6	9.1	9.1	9.1
	2	4.2	4.2	0.5	1.6	-0.9	-0.9	-0.9
	3	4.2	4.2	0.5	1.6	-0.9	-0.9	-0.9
	4	25.2	25.2	21.5	22.6	20.1	20.1	20.1
	5	31.2	31.2	27.5	28.6	26.1	26.1	26.1
	7	14.2	14.2	10.5	11.6	9.1	9.1	9.1
	8	7.2	7.2	3.5	4.6	2.1	2.1	2.1
EO	1	18.2	18.2	16.5	18.2	13.3	13.3	13.3
	2	8.2	8.2	6.5	8.2	3.3	3.3	3.3
	3	8.2	8.2	6.5	8.2	3.3	3.3	3.3
	4	29.2	29.2	27.5	29.2	24.3	24.3	24.3
	5	35.2	35.2	33.5	35.2	30.3	30.3	30.3
	7	18.2	18.2	16.5	18.2	13.3	13.3	13.3
	8	11.2	11.2	9.5	11.2	6.3	6.3	6.3
SCO	1	11.4	11.4	8.7	9.6	8.0	8.0	8.0
	2	1.4	1.4	-1.3	-0.4	-2.0	-2.0	-2.0
	3	1.4	1.4	-1.3	-0.4	-2.0	-2.0	-2.0
	4	22.4	22.4	19.7	20.6	19.0	19.0	19.0
	5	28.4	28.4	25.7	26.6	25.0	25.0	25.0
	7	11.4	11.4	8.7	9.6	8.0	8.0	8.0
	8	4.4	4.4	1.7	2.6	1.0	1.0	1.0
SWO	1	12.1	12.1	7.9	8.6	7.6	7.6	7.6
	2	2.1	2.1	-2.1	-1.4	-2.4	-2.4	-2.4
	3	2.1	2.1	-2.1	-1.4	-2.4	-2.4	-2.4
	4	23.1	23.1	18.9	19.6	18.6	18.6	18.6
	5	29.1	29.1	24.9	25.6	24.6	24.6	24.6
	7	12.1	12.1	7.9	8.6	7.6	7.6	7.6
	8	5.1	5.1	0.9	1.6	0.6	0.6	0.6

APPENDIX 5 Continued

Soil Moisture Deficit or Surplus (cm) for Future Thermal Regime: Average Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	10.8	10.8	6.6	7.4	6.2	6.2	6.2
	2	0.8	0.8	-3.4	-2.6	-3.8	-3.8	-3.8
	3	0.8	0.8	-3.4	-2.6	-3.8	-3.8	-3.8
	4	21.8	21.8	17.6	18.4	17.2	17.2	17.2
	5	27.8	27.8	23.6	24.4	23.2	23.2	23.2
	7	10.8	10.8	6.6	7.4	6.2	6.2	6.2
	8	3.8	3.8	-0.4	0.4	-0.8	-0.8	-0.8
	1	2.8	2.8	-0.6	-0.6	1.1	1.1	1.1
CO	2	-7.2	-7.2	-10.6	-10.6	-8.9	-8.9	-8.9
	3	-7.2	-7.2	-10.6	-10.6	-8.9	-8.9	-8.9
	4	13.8	13.8	10.4	10.4	12.1	12.1	12.1
	5	19.8	19.8	16.4	16.4	18.1	18.1	18.1
	7	2.8	2.8	-0.6	-0.6	1.1	1.1	1.1
	8	-4.2	-4.2	-7.6	-7.6	-5.9	-5.9	-5.9
	1	0.6	0.6	-0.4	-0.9	2.6	2.6	2.6
	2	-9.4	-9.4	-10.4	-10.9	-7.4	-7.4	-7.4
WO	3	-9.4	-9.4	-10.4	-10.9	-7.4	-7.4	-7.4
	4	11.6	11.6	10.6	10.1	13.6	13.6	13.6
	5	17.6	17.6	16.6	16.1	19.6	19.6	19.6
	7	0.6	0.6	-0.4	-0.9	2.6	2.6	2.6
	8	-6.4	-6.4	-7.4	-7.9	-4.4	-4.4	-4.4
	1	4.2	4.2	0.7	0.8	2.6	2.6	2.6
	2	-5.8	-5.8	-9.3	-9.2	-7.4	-7.4	-7.4
	3	-5.8	-5.8	-9.3	-9.2	-7.4	-7.4	-7.4
EO	4	15.2	15.2	11.7	11.8	13.6	13.6	13.6
	5	21.2	21.2	17.7	17.8	19.6	19.6	19.6
	7	4.2	4.2	0.7	0.8	2.6	2.6	2.6
	8	-2.8	-2.8	-6.3	-6.2	-4.4	-4.4	-4.4
	1	-0.8	-0.8	-1.1	-1.6	2.4	2.4	2.4
	2	-10.8	-10.8	-11.1	-11.6	-7.6	-7.6	-7.6
	3	-10.8	-10.8	-11.1	-11.6	-7.6	-7.6	-7.6
	4	10.2	10.2	9.9	9.4	13.4	13.4	13.4
SCO	5	16.2	16.2	15.9	15.4	19.4	19.4	19.4
	7	-0.8	-0.8	-1.1	-1.6	2.4	2.4	2.4
	8	-7.8	-7.8	-8.1	-8.6	-4.6	-4.6	-4.6
	1	-1.8	-1.8	-1.1	-1.8	2.8	2.8	2.8
	2	-11.8	-11.8	-11.1	-11.8	-7.2	-7.2	-7.2
	3	-11.8	-11.8	-11.1	-11.8	-7.2	-7.2	-7.2
	4	9.2	9.2	9.9	9.2	13.8	13.8	13.8
	5	15.2	15.2	15.9	15.2	19.8	19.8	19.8
SWO	7	-1.8	-1.8	-1.1	-1.8	2.8	2.8	2.8
	8	-8.8	-8.8	-8.1	-8.8	-4.2	-4.2	-4.2

APPENDIX 5 Continued

Soil Moisture Deficit or Surplus (cm) for Future Thermal Regime: Low Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	-0.4	-0.4	-2.2	-2.1	-0.6	-0.6	-0.6
	2	-10.4	-10.4	-12.2	-12.1	-10.6	-10.6	-10.6
	3	-10.4	-10.4	-12.2	-12.1	-10.6	-10.6	-10.6
	4	10.6	10.6	8.8	8.9	10.4	10.4	10.4
	5	16.6	16.6	14.8	14.9	16.4	16.4	16.4
	7	-0.4	-0.4	-2.2	-2.1	-0.6	-0.6	-0.6
	8	-7.4	-7.4	-9.2	-9.1	-7.6	-7.6	-7.6
		-8.2	-8.2	-8.6	-9.1	-5.0	-5.0	-5.0
CO	1	-18.2	-18.2	-18.6	-19.1	-15.0	-15.0	-15.0
	2	-18.2	-18.2	-18.6	-19.1	-15.0	-15.0	-15.0
	3	-18.2	-18.2	-18.6	-19.1	-15.0	-15.0	-15.0
	4	2.8	2.8	2.4	1.9	6.0	6.0	6.0
	5	8.8	8.8	8.4	7.9	12.0	12.0	12.0
	7	-8.2	-8.2	-8.6	-9.1	-5.0	-5.0	-5.0
	8	-15.2	-15.2	-15.6	-16.1	-12.0	-12.0	-12.0
		-14.6	-14.6	-11.4	-12.8	-5.8	-5.8	-5.8
WO	1	-24.6	-24.6	-21.4	-22.8	-15.8	-15.8	-15.8
	2	-24.6	-24.6	-21.4	-22.8	-15.8	-15.8	-15.8
	3	-24.6	-24.6	-21.4	-22.8	-15.8	-15.8	-15.8
	4	-3.6	-3.6	-0.4	-1.8	5.2	5.2	5.2
	5	2.4	2.4	5.6	4.2	11.2	11.2	11.2
	7	-14.6	-14.6	-11.4	-12.8	-5.8	-5.8	-5.8
	8	-21.6	-21.6	-18.4	-19.8	-12.8	-12.8	-12.8
		-7.5	-7.5	-7.7	-8.3	-3.9	-3.9	-3.9
EO	1	-17.5	-17.5	-17.7	-18.3	-13.9	-13.9	-13.9
	2	-17.5	-17.5	-17.7	-18.3	-13.9	-13.9	-13.9
	3	-17.5	-17.5	-17.7	-18.3	-13.9	-13.9	-13.9
	4	3.5	3.5	3.3	2.7	7.1	7.1	7.1
	5	9.5	9.5	9.3	8.7	13.1	13.1	13.1
	7	-7.5	-7.5	-7.7	-8.3	-3.9	-3.9	-3.9
	8	-14.5	-14.5	-14.7	-15.3	-10.9	-10.9	-10.9
		-16.0	-16.0	-12.1	-13.5	-6.1	-6.1	-6.1
SCO	1	-26.0	-26.0	-22.1	-23.5	-16.1	-16.1	-16.1
	2	-26.0	-26.0	-22.1	-23.5	-16.1	-16.1	-16.1
	3	-26.0	-26.0	-22.1	-23.5	-16.1	-16.1	-16.1
	4	-5.0	-5.0	-1.1	-2.5	4.9	4.9	4.9
	5	1.0	1.0	4.9	3.5	10.9	10.9	10.9
	7	-16.0	-16.0	-12.1	-13.5	-6.1	-6.1	-6.1
	8	-23.0	-23.0	-19.1	-20.5	-13.1	-13.1	-13.1
		-17.0	-17.0	-12.0	-13.6	-5.7	-5.7	-5.7
SWO	1	-27.0	-27.0	-22.0	-23.6	-15.7	-15.7	-15.7
	2	-27.0	-27.0	-22.0	-23.6	-15.7	-15.7	-15.7
	3	-27.0	-27.0	-22.0	-23.6	-15.7	-15.7	-15.7
	4	-6.0	-6.0	-1.0	-2.6	5.3	5.3	5.3
	5	0.0	0.0	5.0	3.4	11.3	11.3	11.3
	7	-17.0	-17.0	-12.0	-13.6	-5.7	-5.7	-5.7
	8	-24.0	-24.0	-19.0	-20.6	-12.7	-12.7	-12.7

APPENDIX 5 Continued

Soil Moisture Deficit or Surplus (cm) for Future Thermal Regime: High Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	BARLEY	OATS
NO	1	27.3	27.3	19.6	21.4	16.2	16.2	16.2
	2	17.3	17.3	9.6	11.4	6.2	6.2	6.2
	3	17.3	17.3	9.6	11.4	6.2	6.2	6.2
	4	38.3	38.3	30.6	32.4	27.2	27.2	27.2
	5	44.3	44.3	36.6	38.4	33.2	33.2	33.2
	7	27.3	27.3	19.6	21.4	16.2	16.2	16.2
	8	20.3	20.3	12.6	14.4	9.2	9.2	9.2
	1	9.1	9.1	3.9	4.3	4.6	4.6	4.6
CO	2	-0.9	-0.9	-6.1	-5.7	-5.4	-5.4	-5.4
	3	-0.9	-0.9	-6.1	-5.7	-5.4	-5.4	-5.4
	4	20.1	20.1	14.9	15.3	15.6	15.6	15.6
	5	26.1	26.1	20.9	21.3	21.6	21.6	21.6
	7	9.1	9.1	3.9	4.3	4.6	4.6	4.6
	8	2.1	2.1	-3.1	-2.7	-2.4	-2.4	-2.4
	1	10.5	10.5	6.7	6.8	8.1	8.1	8.1
	2	0.5	0.5	-3.3	-3.2	-1.9	-1.9	-1.9
WO	3	0.5	0.5	-3.3	-3.2	-1.9	-1.9	-1.9
	4	21.5	21.5	17.7	17.8	19.1	19.1	19.1
	5	27.5	27.5	23.7	23.8	25.1	25.1	25.1
	7	10.5	10.5	6.7	6.8	8.1	8.1	8.1
	8	3.5	3.5	-0.3	-0.2	1.1	1.1	1.1
	1	15.6	15.6	9.0	9.7	8.9	8.9	8.9
	2	5.6	5.6	-1.0	-0.3	-1.1	-1.1	-1.1
	3	5.6	5.6	-1.0	-0.3	-1.1	-1.1	-1.1
EO	4	26.6	26.6	20.0	20.7	19.9	19.9	19.9
	5	32.6	32.6	26.0	26.7	25.9	25.9	25.9
	7	15.6	15.6	9.0	9.7	8.9	8.9	8.9
	8	8.6	8.6	2.0	2.7	1.9	1.9	1.9
	1	9.1	9.1	6.1	6.1	7.8	7.8	7.8
	2	-0.9	-0.9	-3.9	-3.9	-2.2	-2.2	-2.2
	3	-0.9	-0.9	-3.9	-3.9	-2.2	-2.2	-2.2
	4	20.1	20.1	17.1	17.1	18.8	18.8	18.8
SCO	5	26.1	26.1	23.1	23.1	24.8	24.8	24.8
	7	9.1	9.1	6.1	6.1	7.8	7.8	7.8
	8	2.1	2.1	-0.9	-0.9	0.8	0.8	0.8
	1	8.2	8.2	6.1	5.9	8.3	8.3	8.3
	2	-1.8	-1.8	-3.9	-4.1	-1.7	-1.7	-1.7
	3	-1.8	-1.8	-3.9	-4.1	-1.7	-1.7	-1.7
	4	19.2	19.2	17.1	16.9	19.3	19.3	19.3
	5	25.2	25.2	23.1	22.9	25.3	25.3	25.3
SWO	7	8.2	8.2	6.1	5.9	8.3	8.3	8.3
	8	1.2	1.2	-0.9	-1.1	1.3	1.3	1.3

APPENDIX 5 Continued

Precipitation (mm) for Crop Growing Periods

Region NO	Scen. Cur	Precip. Normal Low High	Fodder Corn 325 222 426	Grain Corn 325 222 426	Soybeans 325 222 426	Potatoes 325 222 426	Wheat 278 190 364	Barley 278 190 364	Oats 278 190 364
CO	Cur	Normal	360	360	316	341	243	243	243
		Low	263	263	231	249	178	178	178
		High	469	469	412	444	317	317	317
	Fut	Normal	441	441	319	343	245	245	245
		Low	331	331	239	258	184	184	184
		High	504	504	364	392	280	280	280
WO	Cur	Normal	390	390	325	350	250	250	250
		Low	276	276	230	248	177	177	177
		High	477	477	398	428	306	306	306
	Fut	Normal	447	447	323	348	248	248	248
		Low	295	295	213	229	164	164	164
		High	546	546	394	425	303	303	303
EO	Cur	Normal	385	385	358	385	275	275	275
		Low	294	294	273	294	210	210	210
		High	484	484	449	484	346	346	346
	Fut	Normal	466	466	336	362	259	259	259
		Low	349	349	252	271	194	194	194
		High	580	580	419	451	322	322	322
SCO	Cur	Normal	378	378	319	344	245	245	245
		Low	267	267	225	243	173	173	173
		High	459	459	387	417	298	298	298
	Fut	Normal	442	442	319	344	246	246	246
		Low	290	290	209	225	161	161	161
		High	541	541	391	421	300	300	300
SWO	Cur	Normal	406	406	316	340	243	243	243
		Low	279	279	217	234	167	167	167
		High	495	495	385	415	296	296	296
	Fut	Normal	442	442	319	344	246	246	246
		Low	290	290	210	226	161	161	161
		High	542	542	391	421	301	301	301

APPENDIX 5 Continued

Potential Evapotranspiration (mm) for the Growing Period

Region	Scenario	Fodder Corn	Grain Corn	Soybeans	Potatoes	Wheat	Barley	Oats
NO	Cur	374	374	374	374	341	341	341
	Fut	502	502	446	466	367	367	367
CO	Cur	414	414	428	444	360	360	360
	Fut	563	563	475	499	384	384	384
WO	Cur	485	485	443	462	365	365	365
	Fut	591	591	477	507	372	372	372
EO	Cur	452	452	434	452	363	363	363
	Fut	574	574	479	504	383	383	383
SCO	Cur	495	495	450	471	368	368	368
	Fut	600	600	480	510	372	372	372
SWO	Cur	524	524	456	479	370	370	370
	Fut	610	610	480	512	368	368	368

Maximum Growing Period for Field Crops

Crop	Maximum Growing Period (Days)
Fodder Corn	180
Grain Corn	180
Soybeans	130
Potatoes	140
Wheat	100
Barley	100
Oats	100

APPENDIX 6: EFFECTS OF CLIMATIC CHANGE AND VARIABILITY IN PRECIPITATION ON FIELD CROP YIELDS

Current Thermal Regime: Average Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	HAY	BARLEY	OATS
NO	1	18007	50	0	5279	872	9919	3518	3021
	2	12965	36	0	3959	689	6667	3997	3434
	3	12965	36	0	3959	689	6667	3997	3434
	4	11539	32	0	3420	534	8817	1496	1286
	5	5510	15	0	1687	255	5887	575	494
	7	18007	50	0	5279	872	9919	3518	3021
	8	14945	41	0	4487	776	7538	3997	3434
		33917	6586	2067	15917	2808	9119	3825	3775
CO	2	23741	4610	1335	10257	1852	5915	3596	3548
	3	23741	4610	0	10257	1852	5915	3596	3548
	4	22222	4316	1550	12734	2151	8427	1901	1876
	5	10531	2045	775	7004	1116	5786	861	849
	7	33917	6586	2067	15917	2808	9119	3825	3775
	8	27473	5335	0	12026	2121	6771	3825	3775
	1	25469	6852	2325	21893	3494	9825	4884	4783
	2	15393	4142	1484	13841	2280	6301	4640	4544
WO	3	15393	4142	0	13841	2280	6301	4640	4544
	4	20151	5422	1781	18118	2648	8912	2427	2376
	5	10580	2846	913	10305	1357	6136	1077	1055
	7	25469	6852	2325	21893	3494	9825	4884	4783
	8	18472	4970	0	16357	2648	7211	4884	4783
	1	26693	5386	1937	18749	3451	9927	4692	3579
	2	17351	3501	1433	13124	2450	6820	4887	3728
	3	17351	3501	0	13124	2450	6820	4887	3728
EO	4	18258	3684	1227	12959	2311	9151	2111	1611
	5	8889	1793	593	6497	1133	6249	880	671
	7	26693	5386	1937	18749	3451	9927	4692	3579
	8	20287	4094	0	14811	2795	7648	4887	3728
	1	27876	6851	1870	20762	3384	10844	4886	4835
	2	16121	3962	1156	12914	2207	7427	4495	4448
	3	16121	3962	0	12914	2207	7427	4495	4448
	4	24182	5943	1513	18230	2648	9265	2498	2471
SCO	5	13904	3418	823	10939	1407	6290	1143	1131
	7	27876	6851	1870	20762	3384	10844	4886	4835
	8	19480	4788	0	15192	2538	8354	4886	4835
	1	28484	7346	2209	19753	3371	11156	4919	4765
	2	16130	4160	1335	11903	2148	7646	4476	4336
	3	16130	4160	0	11903	2148	7646	4476	4336
	4	24709	6373	1849	18234	2666	9539	2585	2504
	5	14208	3665	1040	11396	1433	6470	1173	1136
SWO	7	28484	7346	2209	19753	3371	11156	4919	4765
	8	19904	5134	0	14182	2519	8602	4919	4765

NOTE: Land type 6 is physically unsuitable for all crops except pasture. The yield for each crop included in this project on land type 6 in all regions is zero under all scenarios.

For grain corn, soybeans, wheat, hay, barley and oats, the dry weight yields are reported.

For fodder corn and potatoes, the fresh weight yields are reported.

Yield levels are estimated assuming average management practices and current levels of technology.

APPENDIX 6 Continued

Current Thermal Regime: Low Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	HAY	BARLEY	OATS
NO	1	12785	35	0	3906	724	6127	3997	3434
	2	6302	17	0	2270	437	3868	3317	2849
	3	6302	17	0	2270	437	3868	3317	2849
	4	12965	36	0	3800	628	6130	2331	2003
	5	8103	23	0	2375	369	4376	1097	942
	7	12785	35	0	3906	724	6127	3997	3434
	8	8283	23	0	2745	524	4488	3717	3193
	1	24080	4676	1442	10788	2180	5814	3825	3775
CO	2	11871	2306	689	5129	1195	3603	2792	2756
	3	11871	2306	0	5129	1195	3603	2792	2756
	4	24420	4742	1550	12097	2151	5720	2507	2474
	5	15263	2963	969	7958	1344	4079	1222	1206
	7	24080	4676	1442	10788	2180	5814	3825	3775
	8	15602	3029	0	6897	1493	4206	3175	3133
	1	13994	3765	1509	13841	2611	5623	4884	4783
	2	4199	1130	668	5788	1397	3431	3468	3396
WO	3	4199	1130	0	5788	1397	3431	3468	3396
	4	18136	4880	1763	16126	2648	5474	3271	3203
	5	12595	3389	1113	11324	1655	3938	1604	1571
	7	13994	3765	1509	13841	2611	5623	4884	4783
	8	6997	1883	0	8304	1766	4025	3956	3874
	1	18418	3716	1530	13499	2864	7394	4887	3728
	2	8809	1778	872	7687	1725	5050	4056	3095
	3	8809	1778	0	7687	1725	5050	4056	3095
EO	4	19219	3878	1394	13499	2485	6959	2850	2174
	5	12012	2423	845	8437	1460	4905	1364	1040
	7	18418	3716	1530	13499	2864	7394	4887	3728
	8	11745	2370	0	9374	2070	5665	4496	3430
	1	14778	3632	1198	12660	2538	6850	4886	4835
	2	2687	660	483	4811	1325	4603	3371	3336
	3	2687	660	0	4811	1325	4603	3371	3336
	4	20071	4933	1437	15496	2648	6551	3341	3307
SCO	5	15113	3715	945	11394	1655	4652	1649	1631
	7	14778	3632	1198	12660	2538	6850	4886	4835
	8	6381	1568	0	7090	1692	5195	3860	3819
	1	13041	3363	1335	11396	2444	7061	4869	4717
	2	686	177	462	3545	1223	4786	3246	3145
	3	686	177	0	3545	1223	4786	3246	3145
	4	19026	4907	1664	14587	2666	6923	3470	3362
	5	15134	3903	1156	11168	1667	4913	1727	1673
SWO	7	13041	3363	1335	11396	2444	7061	4869	4717
	8	4461	1151	0	5825	1592	5390	3738	3621

APPENDIX 6 Continued

Current Thermal Regime: High Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	HAY	BARLEY	OATS
NO	1	16566	46	0	4910	803	9895	2398	2060
	2	18007	50	0	5279	872	7291	3677	3158
	3	18007	50	0	5279	872	7291	3677	3158
	4	6872	19	0	2243	352	7772	662	569
	5	2512	7	0	950	146	4826	72	62
	7	16566	46	0	4910	803	9895	2398	2060
	8	18007	50	0	5279	872	8147	3317	2849
	1	30864	5993	2153	17685	2987	8330	3098	3058
CO	2	33917	6586	2024	16094	2569	5653	3825	3775
	3	33917	6586	0	16094	2569	5653	3825	3775
	4	12698	2466	1054	9550	1677	6965	1239	1223
	5	4579	889	455	4457	780	4541	431	425
	7	30864	5993	2153	17685	2987	8330	3098	3058
	8	33917	6586	0	17685	2867	6456	3825	3775
	1	27988	7530	2474	25164	3677	8319	4250	4161
	2	24070	6476	2103	20132	2979	5582	4884	4783
WO	3	24070	6476	0	20132	2979	5582	4884	4783
	4	14912	4012	1390	15582	2198	6824	1758	1721
	5	6675	1796	635	7587	1059	4466	682	668
	7	27988	7530	2474	25164	3677	8319	4250	4161
	8	27148	7304	0	22397	3310	6413	4884	4783
	1	26426	5333	1840	18561	3451	10347	3568	2722
	2	26693	5386	1937	18749	3244	7403	4887	3728
	3	26693	5386	0	18749	3244	7403	4887	3728
EO	4	11531	2327	795	8774	1714	8858	1302	993
	5	4685	945	323	3881	776	5791	374	285
	7	26426	5333	1840	18561	3451	10347	3568	2722
	8	26693	5386	0	18749	3451	8291	4692	3579
	1	33586	8255	2101	25320	3678	9815	4397	4351
	2	25525	6274	1639	18737	2832	6878	4886	4835
	3	25525	6274	0	18737	2832	6878	4886	4835
	4	20313	4992	1271	16772	2304	8171	1899	1880
SCO	5	9521	2340	596	8318	1109	5318	748	740
	7	33586	8255	2101	25320	3678	9815	4397	4351
	8	29219	7181	0	21016	3200	7736	4886	4835
	1	34318	8851	2568	25325	3704	9962	4476	4336
	2	27111	6992	1952	17727	2815	7013	4919	4765
	3	27111	6992	0	17727	2815	7013	4919	4765
	4	20261	5225	1609	17322	2346	8357	1948	1887
	5	9266	2390	763	8661	1133	5426	797	772
SWO	7	34318	8851	2568	25325	3704	9962	4476	4336
	8	30887	7966	0	20260	3185	7874	4919	4765

APPENDIX 6 Continued

Future Thermal Regime: Average Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	HAY	BARLEY	OATS
NO	1	35455	9144	2367	22724	3243	9892	4123	3994
	2	26237	6767	1681	15536	2303	6688	4295	4160
	3	26237	6767	0	15536	2303	6688	4295	4160
	4	21954	5663	1551	16529	2171	9041	1856	1797
	5	10370	2675	746	8348	1065	6119	773	749
	7	35455	9144	2367	22724	3243	9892	4123	3994
	8	30137	7773	0	17623	2627	7604	4295	4160
	1	31400	8099	1744	15449	2617	8645	3981	3857
CO	2	17832	4599	991	8888	1624	5540	3464	3356
	3	17832	4599	0	8888	1624	5540	3464	3356
	4	27911	7199	1550	15237	2165	7988	2207	2138
	5	16398	4229	920	9524	1218	5465	1022	989
	7	31400	8099	1744	15449	2617	8645	3981	3857
	8	21709	5599	0	10793	1925	6401	3862	3741
	1	27305	7043	1778	15308	2767	9570	3995	3870
	2	14021	3617	1019	8717	1775	6044	3675	3560
WO	3	14021	3617	0	8717	1775	6044	3675	3560
	4	26567	6852	1561	15308	2165	8481	2071	2006
	5	16604	4283	917	9568	1151	5811	935	905
	7	27305	7043	1778	15308	2767	9570	3995	3870
	8	18080	4664	0	10631	2075	6980	3995	3870
	1	33866	8735	1877	16789	2831	10682	4086	3958
	2	20084	5180	1127	10030	1815	7437	3759	3641
	3	20084	5180	0	10030	1815	7437	3759	3641
EO	4	28353	7313	1590	15698	2215	10142	2118	2052
	5	15772	4067	905	9812	1177	6966	956	926
	7	33866	8735	1877	16789	2831	10682	4086	3958
	8	24021	6195	0	11992	2123	8328	4086	3958
	1	25838	6664	1706	14846	2733	12117	3987	3863
	2	12357	3188	971	8059	1772	8395	3629	3515
	3	12357	3188	0	8059	1772	8395	3629	3515
	4	26960	6954	1555	15269	2162	10393	2067	2003
SCO	5	16850	4346	942	9544	1163	7038	951	922
	7	25838	6664	1706	14846	2733	12117	3987	3863
	8	16476	4250	0	10180	2042	9497	3987	3863
	1	23668	6104	1688	14503	2773	9497	3959	3836
	2	10559	2723	962	7987	1789	9497	3682	3567
	3	10559	2723	0	7987	1789	9497	3682	3567
	4	26216	6761	1538	15134	2147	9497	2024	1961
	5	16385	4226	932	9458	1127	9497	908	881
SWO	7	23668	6104	1688	14503	2773	9497	3959	3836
	8	14564	3757	0	9879	2087	9497	3959	3836

APPENDIX 6 Continued

Future Thermal Regime: Low Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	HAY	BARLEY	OATS
NO	1	24818	6401	1775	15768	2659	6350	4295	4160
	2	12055	3109	971	8579	1589	3975	3522	3412
	3	12055	3109	0	8579	1589	3975	3522	3412
	4	25528	6584	1704	16695	2335	6325	2536	2456
	5	15955	4115	1065	10435	1387	4531	1218	1180
	7	24818	6401	1775	15768	2659	6350	4295	4160
	8	15955	4115	0	10667	1913	4646	3908	3786
	1	16282	4199	1141	9735	2015	5463	3981	3857
CO	2	2326	600	409	3175	1022	3257	2668	2584
	3	2326	600	0	3175	1022	3257	2668	2584
	4	22608	5831	1411	12342	2165	5432	2780	2693
	5	17445	4499	969	9524	1354	3882	1379	1337
	7	16282	4199	1141	9735	2015	5463	3981	3857
	8	6590	1700	0	5079	1323	3876	3065	2970
	1	7011	1808	954	7442	1925	5283	3875	3754
	2	0	0	217	638	962	3057	2557	2477
WO	3	0	0	0	638	962	3057	2557	2477
	4	15674	4043	1280	10562	2165	5207	2848	2759
	5	13283	3426	976	8420	1354	3790	1438	1394
	7	7011	1808	954	7442	1925	5283	3875	3754
	8	0	0	0	2764	1233	3673	2957	2864
	1	17720	4571	1237	10684	2184	7393	4086	3958
	2	3544	914	486	3707	1169	5049	2901	2810
	3	3544	914	0	3707	1169	5049	2901	2810
EO	4	23816	6143	1495	13030	2215	6957	2736	2651
	5	17720	4571	994	9812	1385	4904	1343	1300
	7	17720	4571	1237	10684	2184	7393	4086	3958
	8	7876	2031	0	5887	1477	5663	3310	3206
	1	5243	1352	885	6786	1922	7005	3828	3708
	2	0	0	152	212	931	4687	2552	2472
	3	0	0	0	212	931	4687	2552	2472
	4	14559	3755	1228	10230	2162	6944	2871	2781
SCO	5	12638	3260	972	8207	1352	4912	1454	1408
	7	5243	1352	885	6786	1922	7005	3828	3708
	8	0	0	0	2121	1232	5270	2911	2820
	1	4005	1033	897	6726	1938	7319	3880	3759
	2	0	0	149	210	954	4974	2573	2493
	3	0	0	0	210	954	4974	2573	2493
	4	13108	3381	1215	10139	2147	7178	2822	2734
	5	11633	3001	962	8134	1342	5043	1408	1364
SWO	7	4005	1033	897	6726	1938	7319	3880	3759
	8	0	0	0	2102	1253	5564	2969	2876

APPENDIX 6 Continued

Future Thermal Regime: High Precipitation

REGION	LANDTYPE	FODDER CORN	GRAIN CORN	SOYBEANS	POTATOES	WHEAT	HAY	BARLEY	OATS
NO	1	23755	6127	1988	20638	3113	10373	2706	2621
	2	35455	9144	2367	23188	3243	7718	4123	3994
	3	35455	9144	0	23188	3243	7718	4123	3994
	4	7148	1844	784	9183	1401	8068	835	809
	5	957	247	277	3757	584	4979	135	131
	7	23755	6127	1988	20638	3113	10373	2706	2621
	8	32618	8413	0	23188	3243	8596	3694	3578
	8	38766	9998	2067	18623	2978	7478	3981	3857
CO	2	26361	6799	1335	12063	1985	4949	3941	3818
	3	26361	6799	0	12063	1985	4949	3941	3818
	4	25958	6695	1550	15237	2123	6510	1863	1805
	5	12386	3194	776	8571	1056	4322	806	781
	7	38766	9998	2067	18623	2978	7478	3981	3857
	8	30626	7898	0	13967	2285	5664	3981	3857
	1	36899	9517	2168	20411	3008	8658	3596	3483
	2	26936	6947	1561	13820	2316	5886	3995	3870
WO	3	26936	6947	0	13820	2316	5886	3995	3870
	4	23379	6030	1421	15308	1884	6899	1553	1505
	5	10959	2827	683	7845	907	4475	611	592
	7	36899	9517	2168	20411	3008	8658	3596	3483
	8	30995	7994	0	15733	2617	6758	3995	3870
	1	39379	10157	2209	21803	3077	10480	3554	3443
	2	35835	9242	1745	16134	2461	7401	4086	3958
	3	35835	9242	0	16134	2461	7401	4086	3958
EO	4	19564	5046	1320	14442	1860	8855	1500	1454
	5	8506	2194	617	7163	886	5789	570	552
	7	39379	10157	2209	21803	3077	10480	3554	3443
	8	39379	10157	0	18097	2769	8288	4086	3958
	1	37445	9659	2159	19935	3003	10626	3629	3515
	2	25463	6568	1511	13361	2282	7660	3987	3863
	3	25463	6568	0	13361	2282	7660	3987	3863
	4	25074	6467	1445	15269	1881	9171	1579	1530
SCO	5	11964	3086	700	8016	919	5917	628	608
	7	37445	9659	2159	19935	3003	10626	3629	3515
	8	29582	7630	0	15269	2583	8540	3987	3863
	1	36411	9391	2136	19547	2981	10588	3524	3413
	2	23668	6104	1496	13031	2326	7668	3959	3836
	3	23668	6104	0	13031	2326	7668	3959	3836
	4	25168	6491	1430	15134	1847	9153	1511	1463
	5	12125	3128	692	8039	886	5901	588	570
SWO	7	36411	9391	2136	19547	2981	10588	3524	3413
	8	27673	7137	0	14923	2624	8558	3959	3836

APPENDIX 7: CROP YIELD LEVELS REQUIRED TO OBTAIN ALTERNATIVE RATES OF RETURN

Crop	Threshold Yield Levels (kg/ha) Given Current Economic Conditions		
	High Return	Modest Return	Not Profitable
Grain Corn	≥ 6230	5190 - 6229	< 5190
Oats	≥ 2400	2180 - 2399	< 2180
Barley	≥ 3220	2900 - 3219	< 2900
Wheat	≥ 3380	2440 - 3379	< 2440
Soybeans	≥ 2060	1130 - 2059	< 1130
Fodder Corn	≥ 29100	25600 - 29099	< 25600

NOTE: Adapted from E. Haslett (1983) Yields necessary to attain various margin levels with alternative product prices. Prepared for the Regional Development Branch (Toronto), Agriculture Canada. Toronto.

APPENDIX 8: CURRENT AVAILABILITY OF LAND RESOURCES FOR CROP PRODUCTION IN ONTARIO

REGION	AVAILABILITY OF LAND TYPES								Total
	1	2	3	4	(ha) 5	6	7	8	
NO	130346	41106	28364	24226	77174	30800	3803	7188	343007
CO	125885	22430	21779	11595	19222	102841	43723	32755	380230
WO	665027	63606	64354	40158	96195	101486	119831	33974	1184631
EO	176056	81166	81511	44802	256345	184893	3421	91309	919503
SCO	367879	36946	36829	2023	15955	67094	61352	6775	594853
SWO	794900	165800	151634	338143	140469	31998	134484	3372	1760800
Total	2260093	411054	384471	460947	605360	519112	366614	175373	5183024

NOTE: NO = Northern Ontario EO = Eastern Ontario
CO = Central Ontario SCO = South Central Ontario
WO = Western Ontario SWO = South Western Ontario

Adapted from Land Evaluation Group (1983) Analysis of the production possibilities of Ontario agriculture: Regional assessments of the prospects for sustainable agricultural production. Publication No. LEG-16. University School of Rural Planning and Development, University of Guelph. Guelph.

Estimates of land availability indicate the area currently available for production for the field crops considered in this project.

APPENDIX 9: EFFECTS OF CLIMATIC CHANGE AND VARIABILITY IN PRECIPITATION ON THE ECONOMIC SUITABILITY OF LAND RESOURCES FOR AGRICULTURAL PRODUCTION

Current Thermal Regime

Region	Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
			High Return	Modest Return	Not Profitable
NO	Fodder Corn	Norms	0	0	343007
		Low Prec	0	0	343007
		Hi Prec	0	0	343007
	Grain Corn	Norms	0	0	343007
		Low Prec	0	0	343007
		Hi Prec	0	0	343007
	Soybeans	Norms	0	0	343007
		Low Prec	0	0	343007
		Hi Prec	0	0	343007
	Wheat	Norms	0	0	343007
		Low Prec	0	0	343007
		Hi Prec	0	0	343007
	Barley	Norms	210807	0	132200
		Low Prec	210807	30800	101400
		Hi Prec	107458	0	235549
	Oats	Norms	210807	0	132200
		Low Prec	241607	0	101400
		Hi Prec	107458	0	235549
CO	Fodder Corn	Norms	169608	32755	177867
		Low Prec	0	0	380230
		Hi Prec	349413	0	30817
	Grain Corn	Norms	169608	32755	177867
		Low Prec	0	0	380230
		Hi Prec	179805	169608	30817
	Soybeans	Norms	169608	34025	176597
		Low Prec	0	181203	199027
		Hi Prec	169608	136866	73756
	Wheat	Norms	0	169608	210622
		Low Prec	0	0	380230
		Hi Prec	0	246572	133658
	Barley	Norms	246572	0	133658
		Low Prec	202363	0	177867
		Hi Prec	179805	169608	30817
	Oats	Norms	246572	0	133658
		Low Prec	361008	0	19222
		Hi Prec	349413	0	30817

APPENDIX 9 Continued

Region	Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
			High Return	Modest Return	Not Profitable
WO	Fodder Corn	Norms	0	0	1184631
		Low Prec	0	0	1184631
		Hi Prec	0	818832	365799
	Grain Corn	Norms	784858	40158	359615
		Low Prec	0	0	1184631
		Hi Prec	946792	101486	136353
	Soybeans	Norms	784858	103764	296009
		Low Prec	0	921211	263420
		Hi Prec	848464	141644	194523
	Wheat	Norms	784858	74132	325641
		Low Prec	0	825016	359615
		Hi Prec	784858	263420	136353
	Barley	Norms	946792	0	237839
		Low Prec	986950	101486	96195
		Hi Prec	1048278	0	136353
	Oats	Norms	986950	0	197681
		Low Prec	1088436	0	96195
		Hi Prec	1048278	0	136353
EO	Fodder Corn	Norms	0	179477	740026
		Low Prec	0	0	919503
		Hi Prec	0	433463	486040
	Grain Corn	Norms	0	179477	740026
		Low Prec	0	0	919503
		Hi Prec	0	433463	486040
	Soybeans	Norms	0	305445	614058
		Low Prec	0	224279	695224
		Hi Prec	0	445536	473967
	Wheat	Norms	179477	253986	486040
		Low Prec	0	224279	695224
		Hi Prec	270786	347570	301147
	Barley	Norms	433463	0	486040
		Low Prec	618356	44802	256345
		Hi Prec	618356	0	301147
	Oats	Norms	433463	0	486040
		Low Prec	618356	44802	256345
		Hi Prec	618356	0	301147

APPENDIX 9 Continued

Region	Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
			High Return	Modest Return	Not Profitable
SCO	Fodder Corn	Norms	0	429231	165622
		Low Prec	0	0	594853
		Hi Prec	436006	0	158847
	Grain Corn	Norms	429231	2023	163599
		Low Prec	0	0	594853
		Hi Prec	509781	67094	17978
	Soybeans	Norms	0	468200	126653
		Low Prec	0	431254	163599
		Hi Prec	429231	106063	59559
	Wheat	Norms	429231	8798	156824
		Low Prec	0	431254	163599
		Hi Prec	429231	147644	17978
	Barley	Norms	509781	0	85072
		Low Prec	511804	67094	15955
		Hi Prec	576875	0	17978
	Oats	Norms	511804	0	83049
		Low Prec	578898	0	15955
		Hi Prec	576875	0	17978
SWO	Fodder Corn	Norms	0	929384	831416
		Low Prec	0	0	1760800
		Hi Prec	932756	317434	510610
	Grain Corn	Norms	1267527	0	493273
		Low Prec	0	0	1760800
		Hi Prec	1250190	370141	140469
	Soybeans	Norms	929384	503943	327473
		Low Prec	0	1407996	352804
		Hi Prec	929384	535941	295475
	Wheat	Norms	929384	341515	489901
		Low Prec	0	1267527	493273
		Hi Prec	929384	352804	478612
	Barley	Norms	1250190	0	510610
		Low Prec	1588333	0	172467
		Hi Prec	1282188	0	478612
	Oats	Norms	1588333	0	172467
		Low Prec	1620331	0	140469
		Hi Prec	1282188	0	478612

APPENDIX 9 Continued

Ontario

Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
		High Return	Modest Return	Not Profitable
Fodder Corn	Norms	169608	1570847	3442569
	Low	0	0	5183024
	Hi	1718175	1569729	1895120
Grain Corn	Norms	2651224	254413	2277387
	Low	0	0	5183024
	Hi	2886568	1141792	1154664
Soybeans	Norms	1883850	1415377	1883797
	Low	0	3165943	2017081
	Hi	2376687	1366050	1440287
Wheat	Norms	2322950	848039	2012035
	Low	0	2748076	2434948
	Hi	2414259	1358010	1410755
Barley	Norms	3597605	0	1585419
	Low	4118613	244182	820229
	Hi	3812960	169608	1200456
Oats	Norms	3977929	0	1205095
	Low	4508636	44802	629586
	Hi	3982568	0	1200456

APPENDIX 9 Continued

Future Thermal Regime

Region	Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
			High Return	Modest Return	Not Profitable
NO	Fodder Corn	Norms	141337	69470	132200
		Low Prec	0	0	343007
		Hi Prec	107458	0	235549
	Grain Corn	Norms	210807	24226	107974
		Low Prec	158375	0	184632
		Hi Prec	107458	134149	101400
	Soybeans	Norms	134149	65332	143526
		Low Prec	0	235549	107458
		Hi Prec	71906	134149	136952
	Wheat	Norms	0	141337	201670
		Low Prec	0	134149	208858
		Hi Prec	0	241607	101400
	Barley	Norms	210807	0	132200
		Low Prec	210807	30800	101400
		Hi Prec	107458	0	235549
	Oats	Norms	210807	0	132200
		Low Prec	265833	0	77174
		Hi Prec	241607	0	101400
CO	Fodder Corn	Norms	169608	11595	199027
		Low Prec	0	0	380230
		Hi Prec	202363	55804	122063
	Grain Corn	Norms	181203	32755	166272
		Low Prec	0	11595	368635
		Hi Prec	258167	102841	19222
	Soybeans	Norms	0	181203	199027
		Low Prec	0	181203	199027
		Hi Prec	169608	136866	73756
	Wheat	Norms	0	169608	210622
		Low Prec	0	0	380230
		Hi Prec	0	169608	210622
	Barley	Norms	246572	0	133658
		Low Prec	169608	32755	177867
		Hi Prec	349413	0	30817
	Oats	Norms	246572	0	133658
		Low Prec	258167	102841	19222
		Hi Prec	349413	0	30817

APPENDIX 9 Continued

Region	Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
			High Return	Modest Return	Not Profitable
WO	Fodder Corn	Norms	0	825016	359615
		Low Prec	0	0	1184631
		Hi Prec	818832	127960	237839
	Grain Corn	Norms	825016	0	359615
		Low Prec	0	0	1184631
		Hi Prec	946792	141644	96195
	Soybeans	Norms	0	825016	359615
		Low Prec	0	40158	1144473
		Hi Prec	784858	205250	194523
	Wheat	Norms	0	784858	399773
		Low Prec	0	0	1184631
		Hi Prec	0	818832	365799
	Barley	Norms	946792	0	237839
		Low Prec	784858	33974	365799
		Hi Prec	1048278	0	136353
	Oats	Norms	946792	0	237839
		Low Prec	986950	0	197681
		Hi Prec	1048278	0	136353
EO	Fodder Corn	Norms	179477	44802	695224
		Low Prec	0	0	919503
		Hi Prec	618356	0	301147
	Grain Corn	Norms	315588	162677	441238
		Low Prec	0	44802	874701
		Hi Prec	618356	0	301147
	Soybeans	Norms	0	305445	614058
		Low Prec	0	224279	695224
		Hi Prec	179477	310861	429165
	Wheat	Norms	0	179477	740026
		Low Prec	0	0	919503
		Hi Prec	0	433463	486040
	Barley	Norms	433463	0	486040
		Low Prec	270786	162677	486040
		Hi Prec	618356	0	301147
	Oats	Norms	433463	0	486040
		Low Prec	663158	0	256345
		Hi Prec	618356	0	301147

APPENDIX 9 Continued

Region	Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
			High Return	Modest Return	Not Profitable
SCO	Fodder Corn	Norms	0	431254	163599
		Low Prec	0	0	594853
		Hi Prec	436006	0	158847
	Grain Corn	Norms	431254	0	163599
		Low Prec	0	0	594853
		Hi Prec	511804	67094	15955
	Soybeans	Norms	0	431254	163599
		Low Prec	0	2023	592830
		Hi Prec	429231	106063	59559
	Wheat	Norms	0	429231	165622
		Low Prec	0	0	594853
		Hi Prec	0	436006	158847
	Barley	Norms	509781	0	85072
		Low Prec	429231	8798	156824
		Hi Prec	576875	0	17978
	Oats	Norms	509781	0	85072
		Low Prec	511804	0	83049
		Hi Prec	576875	0	17978
SWO	Fodder Corn	Norms	0	338143	1422657
		Low Prec	0	0	1760800
		Hi Prec	929384	3372	828044
	Grain Corn	Norms	338143	929384	493273
		Low Prec	0	0	1760800
		Hi Prec	1270899	317434	172467
	Soybeans	Norms	0	1267527	493273
		Low Prec	0	338143	1422657
		Hi Prec	929384	535941	295475
	Wheat	Norms	0	929384	831416
		Low Prec	0	0	1760800
		Hi Prec	0	932756	828044
	Barley	Norms	1250190	0	510610
		Low Prec	929384	3372	828044
		Hi Prec	1282188	0	478612
	Oats	Norms	1250190	0	510610
		Low Prec	1588333	0	172467
		Hi Prec	1282188	0	478612

APPENDIX 9 Continued

Ontario

Crop	Precip. Levels	Area (ha) of Land with Alternative Rates of Return		
		High Return	Modest Return	Not Profitable
Fodder Corn	Norms	490422	1720280	2972322
	Low	0	0	5183024
	Hi	3112399	187136	1883489
Grain Corn	Norms	2302011	1149042	1731971
	Low	158375	56397	4968252
	Hi	3713476	763162	706386
Soybeans	Norms	134149	3075777	1973098
	Low	0	1021355	4161669
	Hi	2564464	1429130	1189430
Wheat	Norms	0	2633895	2549129
	Low	0	134149	5048875
	Hi	0	3032272	2150752
Barley	Norms	3597605	0	1585419
	Low	2794674	272376	2115974
	Hi	3982568	0	1200456
Oats	Norms	3597605	0	1585419
	Low	4274245	102841	805938
	Hi	4116717	0	1066307

APPENDIX 10: EFFECTS OF CLIMATIC CHANGE ON PRODUCTION OPPORTUNITIES FOR HORTICULTURAL CROPS

Map Unit ¹	Scenario ²	Corn Heat Units	Frost Free Growing Period (Days)	Estimated Extreme Minimum January Temp. (C)	Climatic Rating ³ for:		
					Sweet Corn	Grapes	Apples
C1001	C	2925	148	-35.57	G	N	G
	B	4439	207	-29.77	V	P	V
C1002	C	3329	168	-32.68	V	P	V
	B	4905	226	-26.88	V	G	V
C1003	C	2644	148	-35.58	G	N	F
	B	4117	201	-29.78	V	P	V
C1004	C	3109	160	-33.39	V	P	V
	B	4682	220	-27.59	V	G	V
C1005	C	3307	164	-34.11	V	P	V
	B	4855	223	-28.31	V	G	V
C1007	C	2751	142	-35.54	G	N	F
	B	4250	201	-29.74	V	P	V
C1008	C	3060	157	-34.85	G	N	V
	B	4584	214	-29.05	V	P	V
C1009	C	3251	166	-32.93	V	P	V
	B	4852	227	-27.13	V	G	V
C1010	C	2644	148	-35.58	G	N	F
	B	4117	201	-29.78	V	P	V
C1011	C	3038	151	-36.58	G	N	G
	B	4588	214	-30.78	V	P	G
C1012	C	3234	167	-32.59	V	P	V
	B	4847	228	-26.79	V	G	V
C1013	C	3365	174	-31.95	V	P	V
	B	4930	228	-26.15	V	G	V
C1014	C	3298	163	-33.39	V	P	V
	B	4852	221	-27.59	V	G	V
C1015	C	3315	168	-32.68	V	P	V
	B	4892	225	-26.88	V	G	V
C1017	C	2864	146	-35.79	G	N	G
	B	4372	206	-29.99	V	P	V
C1018	C	3038	151	-36.58	G	N	G
	B	4588	214	-30.78	V	P	G
C1019	C	2839	145	-36.10	G	N	G
	B	4363	207	-30.30	V	P	V
C2042	C	1768	103	-47.47	P	N	N
	B	2783	147	-40.77	G	N	F
C2043	C	1694	102	-45.39	P	N	N
	B	2835	153	-38.69	G	N	N
C2044	C	1627	101	-45.11	P	N	N
	B	2770	152	-38.41	G	N	F
C2045	C	2184	119	-47.03	P	N	P
	B	3272	161	-40.33	V	P	G
C2046	C	2491	131	-39.28	P	N	P
	B	3814	177	-33.48	V	P	G
C2047	C	1602	99	-42.79	P	N	N
	B	2772	152	-37.19	G	N	F
C2048	C	2491	131	-39.28	P	N	P
	B	3814	177	-33.48	V	P	G
C2092	C	2148	119	-44.73	P	N	P
	B	3268	163	-39.03	V	P	G

¹ Map units are identified on the Soils of Canada Map (Clayton, J.S., W.A. Ehrlich, D.B. Cann, J.H. Day, and I.B. Marshall. 1977. Soils of Canada, Volumes 1 and 2. Research Branch, Agriculture Canada. Ottawa).

² C = Current Climate B = Future Climate

³ V = Very Good F = Fair N = Not Likely to be Grown
G = Good P = Poor

APPENDIX 10 Continued

Map Unit	Scenario	Corn Heat Units	Frost Free Growing Period (Days)	Estimated Extreme Minimum January Temp. (C)	Climatic Rating for:		
					Sweet Corn	Grapes	Apples
C2093	C	2331	125	-46.26	P	N	P
	B	3580	174	-40.66	V	P	G
C2107	C	1697	99	-45.72	P	N	N
	B	2763	146	-40.02	G	N	F
C2131	C	1885	108	-47.83	P	N	N
	B	2879	148	-41.13	G	N	G
D3002	C	2751	142	-35.54	G	N	F
	B	4250	201	-29.74	V	P	V
D3007	C	2587	135	-37.86	G	N	F
	B	3883	179	-32.06	V	P	G
D3017	C	1848	106	-45.96	P	N	N
	B	2940	153	-39.26	G	N	G
D3018	C	1886	114	-46.01	P	N	N
	B	2982	157	-39.31	G	N	G
D3019	C	1647	96	-48.72	P	N	N
	B	2684	143	-42.02	G	N	F
D3024	C	1612	93	-49.54	P	N	N
	B	2666	141	-42.84	G	N	F
D3025	C	1612	93	-49.54	P	N	N
	B	2666	141	-42.84	G	N	F
D3044	C	2541	132	-38.58	F	N	F
	B	3878	179	-32.78	V	P	G
D3122	C	1735	98	-46.29	P	N	N
	B	2898	148	-40.69	G	N	G
D3123	C	2682	141	-42.06	G	N	F
	B	4055	191	-36.26	V	P	G
D3128	C	2048	114	-47.55	P	N	P
	B	3081	154	-40.85	G	N	G
D3130	C	1627	101	-45.11	P	N	N
	B	2770	152	-38.41	G	N	F
D3131	C	2258	129	-40.56	P	N	P
	B	3631	177	-34.76	V	P	G
D3140	C	1503	96	-49.51	P	N	N
	B	2441	139	-42.81	F	N	P
D3143	C	2751	142	-35.54	G	N	F
	B	4250	201	-29.74	V	P	V
D3147	C	1702	101	-48.52	P	N	N
	B	2680	143	-41.82	G	N	F
D3148	C	1950	110	-47.17	P	N	P
	B	3045	155	-41.57	G	N	G
D3149	C	2021	115	-43.57	P	N	P
	B	3335	164	-37.77	V	P	G
E1001	C	2787	142	-36.91	G	N	F
	B	4191	196	-31.11	V	P	V
E1002	C	2909	148	-35.76	G	N	G
	B	4414	207	-29.96	V	P	V
E1003	C	2644	148	-35.58	G	N	F
	B	4117	201	-29.78	V	P	V
E1004	C	2718	144	-35.55	G	N	F
	B	4216	202	-29.75	V	P	V

APPENDIX 10 Continued

Map Unit	Scenario	Corn Heat Units	Frost Free Growing Period (Days)	Estimated Extreme Minimum January Temp. (C)	Climatic Rating for:		
					Sweet Corn	Grapes	Apples
E1005	C	2661	138	-37.83	G	N	F
	B	4012	185	-32.03	V	P	G
E1006	C	3086	152	-34.33	G	N	V
	B	4648	217	-28.53	V	G	V
E1007	C	3038	151	-36.58	G	N	G
	B	4588	214	-30.78	V	P	G
E1008	C	2750	153	-34.59	G	N	G
	B	4283	209	-28.79	V	G	V
E1009	C	2644	148	-35.58	G	N	F
	B	4117	201	-29.78	V	P	V
E1010	C	2719	140	-37.63	G	N	F
	B	4034	184	-31.83	V	P	G
E1012	C	2790	144	-37.68	G	N	F
	B	4143	194	-31.88	V	P	G
E1013	C	2964	149	-35.92	G	N	G
	B	4414	205	-30.12	V	P	V
E1014	C	2602	149	-35.85	G	N	F
	B	4100	204	-30.05	V	P	V
E1015	C	2431	147	-36.67	F	N	P
	B	3981	207	-30.87	V	P	V
E1016	C	2812	144	-36.04	G	N	G
	B	4327	205	-30.24	V	P	V
E1017	C	2741	142	-35.86	G	N	F
	B	4248	203	-30.06	V	P	V
E1018	C	2741	142	-35.86	G	N	F
	B	4191	200	-30.06	V	P	V
E1019	C	2644	148	-35.58	G	N	F
	B	4117	201	-29.78	V	P	V
E1020	C	2492	129	-38.46	P	N	P
	B	3878	180	-32.66	V	P	G
E2054	C	1602	99	-42.79	P	N	N
	B	2772	152	-37.19	G	N	F
E3071	C	2580	137	-42.13	G	N	F
	B	3976	190	-36.33	V	P	G
E3091	C	2300	130	-40.66	P	N	P
	B	3699	181	-34.86	V	P	G
E3092	C	2580	137	-42.13	G	N	F
	B	3976	190	-36.33	V	P	G
G1002	C	2519	131	-38.42	F	N	F
	B	3839	177	-32.62	V	P	G
G1003	C	2495	130	-38.15	P	N	P
	B	3803	176	-32.35	V	P	G
G1005	C	2979	155	-33.64	G	N	V
	B	4449	207	-27.84	V	G	V
G1006	C	3315	162	-34.62	V	P	V
	B	4852	221	-28.82	V	G	V
G1007	C	3398	167	-31.21	V	P	V
	B	4934	222	-25.41	V	V	V
G1019	C	3060	160	-32.95	G	N	V
	B	4655	220	-27.15	V	G	V

APPENDIX 10 Continued

Map Unit	Scenario	Corn Heat Units	Frost Free Growing Period (Days)	Estimated Extreme Minimum January Temp. (C)	Climatic Rating for:		
					Sweet Corn	Grapes	Apples
G2020	C	2761	142	-37.61	G	N	F
	B	4066	185	-31.81	V	P	G
G2021	C	473	45	-47.45	P	N	N
	B	1383	106	-40.75	F	N	N
G2022	C	575	53	-49.30	P	N	N
	B	1380	99	-42.60	F	N	N
G2024	C	1478	93	-45.04	P	N	N
	B	2605	148	-38.34	G	N	F
G2025	C	1466	91	-46.47	P	N	N
	B	2568	144	-39.77	G	N	F
G2026	C	1933	111	-46.42	P	N	P
	B	2988	154	-40.72	G	N	G
G2030	C	1973	113	-46.48	P	N	P
	B	3034	156	-40.78	G	N	G
G2031	C	1738	101	-46.32	P	N	N
	B	2824	149	-40.62	G	N	G
G2032	C	2353	126	-42.27	P	N	P
	B	3773	181	-36.47	V	P	G
G2035	C	773	63	-49.00	P	N	N
	B	1649	114	-42.30	F	N	N
H1003	C	1656	99	-46.32	P	N	N
	B	2717	147	-39.62	G	N	F
H1005	C	1692	100	-46.58	P	N	N
	B	2741	147	-40.88	G	N	F
H1026	C	2357	123	-46.39	P	N	P
	B	3572	171	-40.79	V	P	G
H3041	C	1077	79	-46.90	P	N	N
	B	2057	131	-40.20	F	N	P
H3042	C	961	73	-45.52	P	N	N
	B	1960	127	-38.82	F	N	P
R1003	C	1635	96	-47.61	P	N	N
	B	2702	145	-40.91	G	N	F
R1004	C	2547	138	-39.86	G	N	F
	B	3831	191	-33.16	V	P	G
R1012	C	1676	98	-47.63	P	N	N
	B	2878	148	-41.83	G	N	G

APPENDIX 11: COMPARISON OF CURRENT CLIMATIC CONDITIONS IN THE CENTRAL UNITED STATES TO THE ALTERED CLIMATIC REGIME IN SOUTH WESTERN ONTARIO

Comparisons of mean daily maximum and minimum temperatures for each month of the year were made between weather stations in the central United States and estimated future values for South Western Ontario. Data are presented for South Western Ontario and for five stations in four states. All of the United States stations are at latitudes in the 38°N to 40°N range. The inland stations are characterized by a continental climate (i.e. greater fluctuations in temperature). Temperatures at the coastal station are modified by the Atlantic Ocean throughout the year and do not show specific seasonal effects. In the case of South Western Ontario, the moderating effects of the lakes result in relatively lower springtime and warmer fall temperatures.

South Western Ontario: Estimated Future Climate 42° 30'N 81° 00'W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum °C	4	4	9	16	22	27	30	30	26	21	13	6
Minimum °C	-4	-4	0	6	10	16	18	18	15	10	5	-3

Average precipitation for season: 906 mm (864x1.049)

Extreme minimum: -27°C

Columbus (Ohio) 39° 58'N 83° 00'W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum °C	3	4	9	16	22	27	29	28	25	18	10	4
Minimum °C	-6	-5	0	6	11	16	18	17	14	8	2	-3

Average precipitation for season: 923 mm

Extreme minimum: -28°C

Decatur (Illinois) 39° 51'N 88° 58'W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum °C	2	5	10	18	24	29	31	30	27	21	11	4
Minimum °C	-8	-5	-1	6	11	16	19	17	14	7	1	-5

Average precipitation for season: 988 mm

Extreme minimum: -26°C

APPENDIX 11 Continued**Indianapolis (Indiana) 39° 46'N 86° 10'W**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum °C	2	4	9	16	22	28	30	29	25	18	10	4
Minimum °C	-6	-5	0	6	12	17	19	18	14	8	2	-3

Average precipitation for season: 1034 mm

Extreme minimum: -29°C

Frederick WFMD (Maryland) 39° 25'N 77° 28'W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum °C	4	6	11	18	23	28	30	29	26	20	12	6
Minimum °C	-5	-4	-1	5	10	15	18	17	13	6	1	-4

Average precipitation for season: 925 mm

Extreme minimum: -24°C

Du Quoin 1 NWW (Illinois) 38° 00'N 89° 15'W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum °C	5	8	13	21	25	30	32	31	28	22	14	7
Minimum °C	-5	-3	1	8	12	17	19	18	14	8	2	-2

Average precipitation for season: 1002 mm

Extreme minimum: -24°C

APPENDIX 12: RECENT REPORTS BY THE LAND EVALUATION GROUP

Procedures for the long-term evaluation of rural land, Publication No. TSC-105. University School of Rural Planning and Development, University of Guelph. Guelph. September 1981.

Land Evaluation Group - Report '83, Publication No. LEG-15. University School of Rural Planning and Development, University of Guelph. Guelph. 1983.

Analysis of the production possibilities of Ontario agriculture: Regional assessments of the prospects for sustainable agricultural production, Volume 1, Publication No. LEG-16. University School of Rural Planning and Development, University of Guelph. Guelph. November 1983.

Potential Applications of a national land evaluation system, Publication No. LEG-17. University School of Rural Planning and Development, University of Guelph. Guelph. December 1983.

Analysis of the production possibilities of Ontario agriculture: Prospects for growth in Ontario's agri-food sector under alternative conditions of supply and demand, Volume II, Publication No. LEG-18. University School of Rural Planning and Development, University of Guelph. Guelph. February 1984.

Analysis of the production possibilities of Ontario agriculture, Executive summary, Publication No. LEG-19. University School of Rural Planning and Development, University of Guelph. Guelph. February 1984.

Assessments of available biophysical resource inventories and crop productivity estimates, Publication No. LEG-20. University School of Rural Planning and Development, University of Guelph. Guelph. November 1984.

Recommended structure for the Canadian Land Evaluation System and development of prototypes, Publication No. LEG-21. University School of Rural Planning and Development, University of Guelph. Guelph. December 1984.

Socio-economic assessment of the implications of climatic change for food production in Ontario, Publication No. LEG-22. University School of Rural Planning and Development, University of Guelph. Guelph. April 1985.

Development of the prototype Canadian Land Evaluation Systems, Publication No. LEG-23. University School of Rural Planning and Development, University of Guelph. Guelph. December 1985.

Applications of the prototype Canadian Land Evaluation Systems to selected issues, Publication No. LEG-24. University School of Rural Planning and Development, University of Guelph. Guelph. December 1985.

Prospects for a Canadian Land Evaluation System: Summary and recommendations,
Publication No. LEG-25. University School of Rural Planning and
Development, University of Guelph. Guelph. March 1986.

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Implications of climate change
and variability for Ontario's
Agri-Food Sector by hand

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